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EXPERIMENTS WITH CLASSES OF STOCK SUITABLE FOR FOREST PLANTING IN THE NORTHERN ROCKY MOUNTAINS [1] [2]

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INTRODUCTION

Except in unusually moist years the survival of planted stock in the northern Rocky Mountains, even on favorable slopes, has not been satisfactory. On good and poor sites alike, the principal cause of the unusual degree of mortality has been the combination of dry soil and dry winds during the hot days of July and August. The results have made it clear that the most important consideration in forest planting in this region is not the choice of a favorable site for planting, but the kinds of planting stock that are best suited to survive the unusually dry conditions, regardless of site.

Records of the United States Weather Bureau taken at Haugan, Mont., near the site of some of the experiments to be described here, indicate that the normal rainfall at that point during June is less than 2 inches, during July about 1 inch, and in August less than 1 inch (*2*).[4] At the same time low humidity, high temperatures, and wind during these months increase evaporation and thus increase the odds against which the planted trees must contend (*4*).

If it were possible to predict with certainty the occurrence of dry years, forest planting in this region could very profitably be confined to moist years, and in this way, with ordinary care, the immediate needs for planting could be met and a high degree of success would be insured. Large investments could be made in planting projects with reasonable assurance of satisfactory survival regardless of the quality of stock. Such reliable forecasts of weather conditions are, however, nowhere available as yet. The only factor directly under control is the class of stock to be grown for planting.

It is the purpose of this article to present the results of experiments in selection of planting stock that may be advantageously applied any year in any of the planting work in this region. The experiments, based on standard practices, were planned to measure the effects of length of roots, age, and size of trees on the survival of the stock in time of drought.

MATERIALS AND METHODS USED

The two tree species used in these experiments were the western white pine (*Pinus monticola*) and the western yellow pine (*P. ponderosa*). The planting sites were chosen only as typical of the class

[1] Received for publication May 9, 1928; issued August, 1928.

[2] Planting by the United States Forest Service in this region is confined at present to that part of the western white pine (*Pinus monticola*) belt in the St. Joe, Coeur d'Alene, Cabinet, Pend Oreille, and Lolo National Forests. Only land which was recently burned over twice is planted, because the areas burned only once usually are reseeded and the forest is satisfactorily reproduced by natural methods.

[3] The following men took part in the early experiments: D. R. Brewster, J. A. Larsen, E. C. Rogers, and P. C. Kitchen. The author made the later experiments.

[4] Reference is made by number (italic) to "Literature cited," p. 1000.

of land on which each species was being extensively planted. The white pine land ranged in elevation from 2,000 to 4,000 feet on northerly slopes and 4,000 to 5,000 feet on westerly and southerly slopes, but no southerly slopes were planted with western white pine unless the soil proved to be very favorable. Western yellow pine plantations were on elevations ranging from 2,000 to 4,000 feet on all slopes. Northerly slopes were, however, invariably planted with white pine rather than yellow pine.

The planting stock was lifted by means of spading forks, except when unusually long (10-inch) roots were desired and a spade was needed. The effort was made to handle uniformly all of the trees in any one experiment. Culling and heeling in followed the usual nursery practice. All of the grading, root pruning, sorting, etc., was done in the shade of a building and with the constant use of wet burlap to prevent drying of roots.

In all experiments, except as otherwise mentioned, planting was by the "slit" method, illustrated in Figure 1, used by the administrative planting crews of the Forest Service in the region. The more careful methods of planting, such as the cone method, may be ideal where cost is a minor consideration, but the slit method has here proved to be most efficient; it has yielded the largest number of living trees per dollar invested, and has shown no evidence of subjecting the trees to root rot or windfall in later life.

Season of planting was given scant consideration. A few experiments and several years of practice indicate that no great difference is to be expected between spring and fall plantings for an average year. Causes of loss of trees may differ somewhat for the two seasons and from one year to another, but the final effect on survival has usually been about equal for spring and fall work. The cold nights and warm days of an Indian summer following fall planting are apparently detrimental. If such weather does not occur, there may be an advantage in fall planting over that of the following spring, but this possibility seems to have no practical value in view of the present impossibility of forecasting such conditions.

As a rule, all trees planted in the field for experimental purposes were individually marked with stakes bearing symbols which designated the test. Sometimes individual serial numbers were used in order that a separate record might be kept for each plant. Lath stakes with tips painted white were used as markers when it was desired to observe the plants closely for three years or more. Otherwise the smaller and less durable, but more easily handled, manufactured pot labels or garden stakes were used to economize labor.

Spacing in plantations was not important in connection with studies that were not to be followed to the stage when crowns close. Hence, the usual method of spacing in plantations was modified to facilitate the taking of the frequent records needed. The different test lots to be compared were usually set in alternate rows, but sometimes, in order to mix them better, the two lots were set in the same row with plants alternating. The rows were of sufficient length to contain from 40 to 200 plants and ran approximately at right angles to contours. These arrangements, together with the use in each test of as uniform a slope as possible, tended to reduce experimental error due to local and unavoidable variations of site. An effort was made either to base each test lot on not less than 400 trees or to repeat the work during several seasons.

LABORATORY WORK

Because of the undesirability of field-planting trees from which detailed anatomical measurements had been taken and which had thereby been exposed to injury from drying, sample lots were devoted

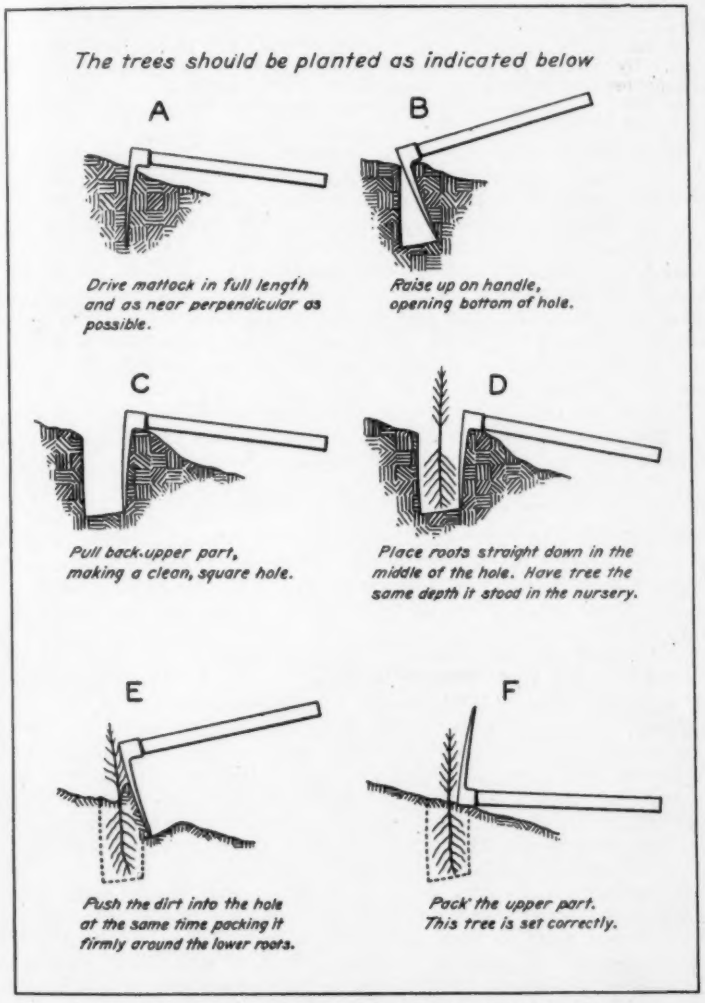
The trees should be planted as indicated below
A
Drive mattock in full length and as near perpendicular as possible.
B
Raise up on handle, opening bottom of hole.
C
Pull back upper part, making a clean, square hole.
D
Place roots straight down in the middle of the hole. Have tree the same depth it stood in the nursery.
E
Push the dirt into the hole at the same time packing it firmly around the lower roots.
F
Pack the upper part. This tree is set correctly.

FIG. 1.—Diagram illustrating the proper use of the slit method of planting trees

exclusively to laboratory examination. These were selected mechanically in order to eliminate the factor of personal judgment. For example, if it was desired to plant 400 and to use 100 in the laboratory, then in counting out the 500, every fifth plant was reserved for

study. In the laboratory every plant was tagged with a serial number and, ordinarily, the following measurements and counts were made:

(1) Diameter at the ground line in millimeters and tenths by means of a micrometer caliper.

(2) Length of stem from ground line to tip of terminal bud in inches and tenths.

(3) Number of primary lateral rootlets in two-length classes: (*a*) 0.5 to 2 inches, and (*b*) over 2 inches long.

(4) Number of secondary lateral rootlets divided into two classes on the same basis. By primary rootlet is meant a branch from the central or tap root, and all branches from the primary rootlets are called secondary.

(5) The length of one needle of average appearance taken from the center of the crown, in inches and tenths.

All measurements were then averaged, and from each lot a few plants having measurements falling close to those of the average tree were selected from the data sheets. The trees thus chosen as typical of stock planted were identified by their tag numbers and were photographed against a translucent screen, using only transmitted light, to obtain satisfactory silhouettes. These plants were severed at the ground line. In some tests the trees were cut just below the crown and also just above the root collar, the intervening section of bare stem being discarded because it functioned only in mechanical support and conduction. After separation, the masses of tops and roots were dried in a water-jacketed oven until no further loss of weight occurred. The averages resulting from the weights of this dried material were useful in judging relative plant development and the balance between top and roots.

EXAMINATION OF PLANTATIONS

In taking records of the plantations an effort was made to make the first examination three weeks or a month after planting in order to observe the early unthriftiness or death due to the shock that plants receive from being moved. Thereafter, during the first season, at least three examinations were made, not oftener than once a month. This was necessary in order to detect the trends of changes leading to the final condition of the trees in the fall. During the second season spring and fall examinations were usually sufficient.

Plants were classified merely as thrifty, unthrifty, and dead, with a notation of any fresh evidences of causes of unthriftiness or death. There was difficulty in fixing a dividing line between thriftiness and unthriftiness, and in the recent experiments a tree was not classed as unthrifty unless this condition was so well marked that it was believed the chances were even that the plant would not recover. Possibly the word "failing" would be more appropriate than "unthrifty." Many trees, suffering from the shock of planting and the first effects of drought, exhibited a partial browning of the needles formed the previous season which gave the plant an unthrifty appearance in the popular sense. Experience indicates that a large number of such plants usually recover, and, therefore, the present policy is to be conservative in calling trees unthrifty. This gives more meaning to a plant class which, at best, depends for its true significance on the accuracy and consistency of personal judgment. With very few exceptions, all test and control lots of trees were planted by the same man, and all records in any series were made by the same person.

TESTS OF AGE CLASSES

Besides showing how old trees are, the term "age class," as applied to forest nursery stock, refers to differences in time of transplanting in the nursery and hence indirectly indicates differences in plant development. Thus the age class 2–0 refers to seedlings which have been in the seed beds for two growing seasons and not transplanted; 1–2 refers to 3-year-old transplants that spent only their first year in the seed beds; and 1–1–1 refers to stock that is 3 years old and was transplanted each year in the nursery. For any given species of tree it is these differences in development that influence the quality of

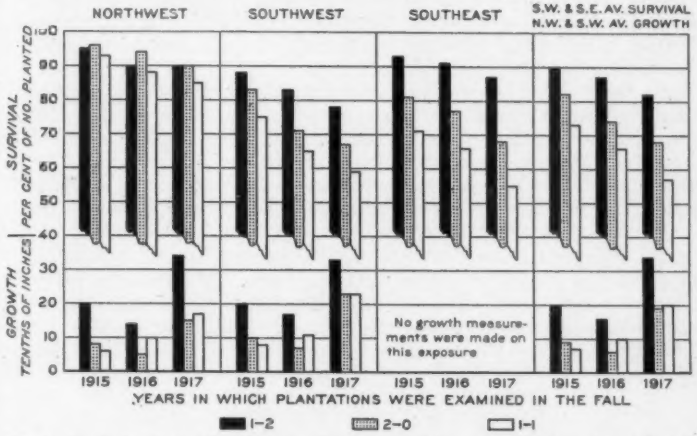

FIG. 2.—Survival and growth of western yellow pine: 7,200 trees of different age classes planted in the spring of 1915 near Wallace, Idaho

stock. In the experiments, age classes were tested in field plantations in order to guide the nursery work.

WESTERN YELLOW PINE

The earliest satisfactory experiments with western yellow pine age classes were started in the spring of 1915 on the Placer Creek drainage, near Wallace, Idaho, on an area severely denuded by the Idaho conflagration of 1910, and typical of the doubly burned-over land in need of reforestation in this region. About 7,200 trees divided equally among three age classes were planted on slopes of three different aspects. All members of the planting crew planted an equal number of trees in each test lot, thus excluding the effect of differences in quality of work on the comparison of later behavior of the trees. Growth measurements were made only on thrifty trees. Although the amount of rainfall during the summer of 1915 was about 2.5 inches above normal for the locality, most of the deaths of trees in the plantations could be attributed to no other cause than drought, and the data therefore indicate directly the relative drought-resisting powers of the several age classes, especially on the more severe sites.

The results of observations of growth and survival during three years are recorded graphically in Figure 2. It may be seen from the

diagram that, on the northwest slope, where the percentage of survival was highest for all age classes, the differences in survival were not great enough to justify any comparison of the classes of stock, but on the two southerly slopes, more definite relationships were apparent. Clearly, the 1–2 stock was best able to survive planting, the 2–0 was intermediate, and the 1–1 stock was least well fitted to survive. Differences in growth between the 2–0 and 1–1 stock were negligible, but the 1–2 stock grew fastest from the start, on all slopes.

With vast areas of forest land lying idle, it is necessary first of all to make each dollar produce as many living trees as possible. Therefore, these age classes were also compared on the basis of cost of survival, or cost of planting per living tree. The cost per thousand survivors of each class was computed by dividing the total cost of planting a thousand trees by the percentage of survival attained and multiplying by 100.

The first cost of planting, including the production of stock, is usually greatest for large transplants. In this case, the 1–2 cost most, the 1–1 next, and the 2–0 least. When the cost of survival was computed, the age classes in the experiment compared as follows: On the favorable northwest slope, the 2–0 stock was most effective, the 1–1 next, and the 1–2 least desirable. On the less favorable southwest and southeast slopes, 1–2 was superior, 2–0 intermediate, and 1–1 inferior. The 1–1 stock made an especially poor showing on the southeast slope from this point of view. Considering the theoretical average cost of survival on all three slopes after three years, the 1–2 stock was most economical, with the 2–0 stock a close second. The survival of 2–0 stock was but 2 per cent more expensive than the 1–2, whereas the 1–1 stock was 23 per cent more expensive.

Very little 2–1 stock has been grown at Savenac. As a general rule, it has been observed in practice that the so-called shock of transplanting or setback in growth which follows the setting of a seedling in a new location persists throughout the following year. In other words, during the first year after transplanting the benefits usually appear to be entirely offset by loss of growth. This condition can be more easily understood from the fact that the 2–1 stock at Savenac Nursery develops quite irregularly, resulting in inferior development of about half of the plants. Culling out about half of the number makes the remainder expensive.

Correspondingly little has been done with 2–1 western yellow pine stock in the way of experimental field planting. The results of two early tests are conflicting. In the fall of 1912 a field test of 2–1 stock was installed at Priest River, Idaho, together with 1–2 and other stock. A year later 78 per cent of the 2–1 were alive and 79 per cent of the 1–2, but the costs per thousand living trees were $23.28 for the 2–1 and $18.94 for the 1–2. In the spring of 1918 another test was made at Haugan, Mont., and was watched during three years. This time the 2–1 led decisively. Its survival was 61 per cent, as compared to 43 per cent for 1–2 the first year, and 54 per cent as against 39 per cent for 1–2 the third year in the field. A comparison of the cost of survival showed the 2–1 stock to be $4.73 cheaper per thousand third-year survivors.

In May, 1923, a test of 2–1, 1–2, and 2–0 western yellow pine was made on a southeast slope of the 1910 burn near Haugan, Mont. The site bore numerous ceanothus bushes and some grass, being typi-

cal of much of the nonforested land of the region. The trees were lifted from the beds at Savenac Nursery on May 1. Not more than 3 per cent were rejected as unsuitable for field use and most of these were culled because of broken roots. In bunches of 50, all plants were root pruned at a point 6.5 inches from the ground line, removing about 3 inches from 2–0 roots, 3.5 inches from the 1–2, and 2 inches from the 2–1. About 50 trees from each lot were set aside for use in the laboratory, and 200 of each of the age classes were planted.

The trees were examined three times during 1923 and twice during 1924 in order to observe the causes of unthriftiness and death. There could be no doubt that drought was the principal cause. No marked differences in the condition of the three lots of trees occurred in the first year until the soil became dry in September. Survival was then 92 per cent of the number planted for 2–1 stock, 90.5 per cent for 1–2, and 84.5 per cent for 2–0. Dry weather started early in the spring of 1924, and thus more deaths than usual occurred during the second growing season, but the age classes still maintained the same order of drought resistance. (See Table 1.)

TABLE 1.—*Comparison of the percentages of survival and top-root ratios of western yellow pine of three different age classes at end of second growing season* [a]

Age class	Alive	Dead	Thrifty	Unthrifty	Weight of plant in top
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2–1 stock	81.8	18.2	80.3	1.5	64.0
1–2 stock	77.1	22.9	76.1	1.0	71.5
2–0 stock	72.9	27.1	69.9	3.0	74.4

[a] Condition in October, 1924, of plantations made in the spring of 1923 on a southeast slope of the 1910 burn near Haugan, Mont.

As is shown in Table 1, field survival increased in the same order in which the percentage of total plant weight in the tops decreased. In other words, survival increased as the top-root ratio decreased. The 2–1, which survived best, had the best balance, whereas the seedling 2–0 stock, which survived least well, had the poorest balance. As will be seen later, this relation between balance and field survival does not always hold true, but the tendency is unmistakable and it should be a help in judging the ability of stock to withstand dry conditions. The appearance of the stock used in the experiments is shown by photographs of representative trees in Figure 3.

These tests indicate that 2–1 stock may excel 1–2 stock in survival if the percentage of weight in the top is less; but, because of the necessity of heavy culling and the consequent higher cost of production of 2–1 stock, it is doubtful if it will ever successfully compete with 1–2 stock. The results agree with the earlier experiments at Wallace in indicating the superiority of 1–2 over 2–0 planting stock.

This evidence of superiority was further corroborated a year later in an experiment testing size classes and length of root. In the spring of 1924, using a uniform grade of medium-sized stock with root systems pruned to a length of 8 inches, 491 plants of 1–2 and 494 plants of 2–0 stock were set out on a dry, rocky, severe south slope. The results are given in Table 2. About one-sixth of the trees in each

lot were dead when first examined, and the two lots were in similar condition when the dry weather started. Mortality with the 2–0 then proceeded at a more rapid rate, especially in July, than with the 1–2 stock, and, although both plantations were virtually destroyed the destruction of the 1–2 was less complete.

TABLE 2.—*Mortality rate of two age classes of western yellow pine in a plantation destroyed by drought* [a]

Age class	Survival at different dates				
	May 26	June 26	July 26	Aug. 26	Nov. 7
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1–2 stock	83.9	73.1	23.8	10.6	7.4
2–0 stock	82.8	62.1	7.7	2.6	1.4

[a] Condition during 1924 on a south slope or the 1910 burn near Haugan, Mont.

The experiments with western yellow pine age classes agree in showing the superior survival of 1–2 over 2–0 stock. When it has a small top-root ratio, 2–1 stock may equal or excel 1–2 in the field; 1–1 is inferior to the other classes. In cost of survival the use of 2–0 stock is scarcely less economical than the use of 1–2 stock. As to other possible age classes it may be said that 1-year-old seedlings, are too small, and that the rather rapid growth of western yellow pine causes seedlings more than 2 years old or transplants more than 3 years old to be too large for economical handling in planting operations at the present time.

Korstian and Baker (*3*), working in the intermountain region obtained the best survival with 2–1 stock. With them the other age classes ranked as follows in descending order of survival: 2–0, 2–2 1–2, 3–0, and 1–1.

WESTERN WHITE PINE

In 1911, at the Priest River Experiment Station [5] in Idaho, a small clearing of about 1 acre was made in a 60-year-old stand of western white pine, Douglas fir (*Pseudotsuga taxifolia*), and western larch (*Larix occidentalis*) on a northeast slope. In the spring of 1915, 100 plants each of 2–0 and 1–2 western white pine were planted in the clearing. In 1921, 66 per cent of the 2–0 and 78 per cent of the 1–2 plants were alive. The 2–0 plants averaged 12 inches and the 1–2 plants 19 inches high.

Another experiment with western white pine age classes near Wallace, Idaho, in the spring of 1915, was combined with a study of aspects of planting sites. About 600 trees were planted in each test lot, or 12,000 trees in all. The details of this experiment have been reported in an earlier paper (*8*); it will be sufficient here to give the results of the work. Figure 4 shows the relative survival of five different age classes at the end of the third growing season after planting. This diagram of actual survival disregards the cost and the growth rates of the living trees. With cost and growth considered, it may be concluded that although in survival of planted trees and in height growth 2–2 western white pine transplants are

[5] Now a field station of the Northern Rocky Mountain Forest Experiment Station.

at the top, with 1–2, 2–1, 2–0, and 1–1 following in descending order, the cost of survival definitely favors 2–0 seedlings on moderate sites, and 2–2 or 1–2 only on the more severe sites.

No further work of this kind was attempted until the fall of 1922. That year dry weather continued so late into the fall that very little planting could be done on the sites selected. On October 27, 400 plants each of 1–2 and 3–0 age classes were planted on a northwest slope of the 1910 burn near Haugan. At the close of the following season the 1–2 stock showed 4 per cent higher survival and 12 per cent more thrifty plants than the 3–0. The growing season had been moist until September, when a deficiency of rainfall caused plants to suffer from drought. Had the summer as well as the fall been dry, the difference in survival would probably have been greater, because the transplants (1–2) had over 10 per cent more of their total weight in their root systems than had the seedlings (3–0). By the end of another growing season the transplants had increased their lead by an additional 4 per cent in survival.

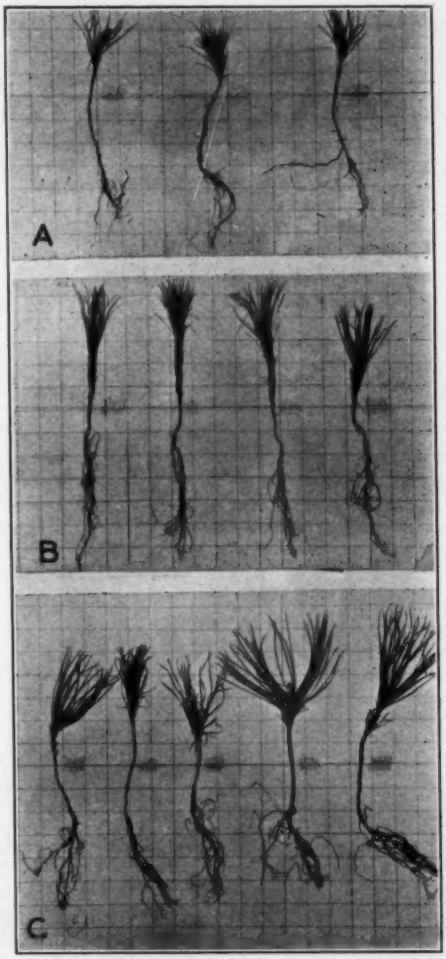

FIG. 3.—Western yellow pine age classes, 1923: A, 2–1 stock; B, 2–0 stock; C, 1–2 stock

The next test, of 1–2, 3–0, and 2–0 western white pine, was started in the fall of 1924, the trees being lifted from the nursery during the last week of September. From the 2–0 stock 3 per cent and from the 3–0 and 1–2 stock 1 per cent of the trees were culled out because of extremely poor development or injury in lifting. Uniformity in the lot of trees was increased by culling out both the largest and smallest individuals until only about half of the original number remained. All roots extending more than 8 inches from the ground line were pruned off at the 8-inch point. Average measurements of

these trees are given in Table 3, and the appearance of representative trees is shown in Figure 5. Four hundred trees of each of these age classes were planted in October, 1924.

TABLE 3.—*Anatomical characteristics of western white pine stock planted in the fall of 1924, as determined by average measurements* [a]

Age class	Stem length	Length of needles	Diameter at ground line	Lateral rootlets		Oven-dry weight	Weight in top	Weight in root
				0.5–2 inches	Over 2 inches			
	Inches	*Inches*	*Millimeters*	*Number*	*Number*	*Grams*	*Per cent*	*Per cent*
1–2 stock	2.4	1.4	2.1	22.2	12.3	1.0	52	48
3–0 stock	4.1	1.5	2.5	20.1	12.8	1.6	67	33
2–0 stock	2.6	1.5	2.0	17.3	7.1	.7	61	39

[a] Basis: Weight measurements, 55 trees; other measurements, 60 trees.

In the following winter, during a period of exceptionally severe weather when the trees were but partly covered with snow, the tops appeared to be seriously injured. However, detailed observation failed to indicate any relation between the relative drought hardiness

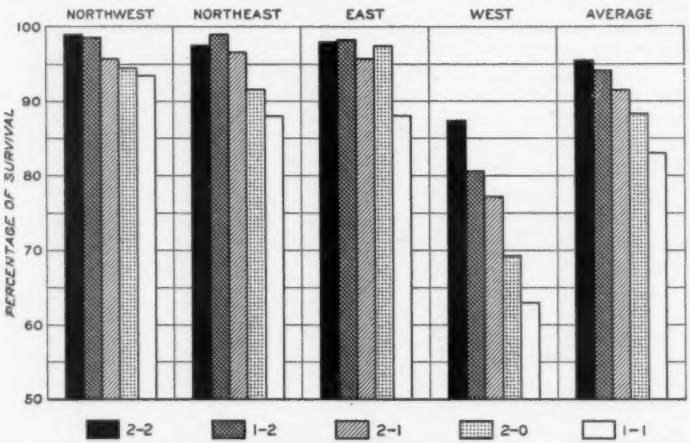

FIG. 4.—Survival of western white pine age classes: 12,000 trees three years after planting in the spring of 1915 near Wallace, Idaho

of the different age classes and either the numbers of buds remaining dormant or the extent of injury to foliage. During the following growing season the winter injury was seen to be less serious than was thought at first; adventitious buds formed readily, and, although the growth of several plants was checked, survival did not appear to be affected. At the end of the season the condition of the plantations was as shown in Table 4.

TABLE 4.—*Condition in September, 1925, of western white pine age classes planted in the fall of 1924, on a northeast aspect near Haugan, Mont.*

Age class	Alive	Dead	Thrifty	Unthrifty
	Per cent	*Per cent*	*Per cent*	*Per cent*
1–2 stock	85.7	14.3	83.7	2.0
3–0 stock	82.7	17.3	78.2	4.5
2–0 stock	72.0	28.0	70.7	1.3

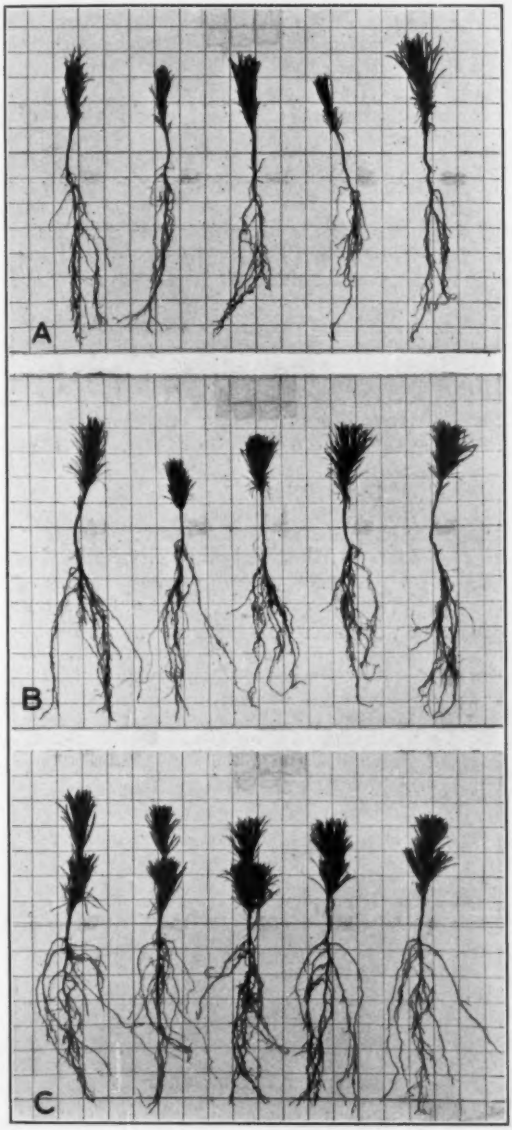

FIG. 5.—Western white pine age classes, 1924: A, 2-0 stock; B, 1-2 stock; C, 3-0 stock

That the 2–0 stock survived least well was not surprising, for its inferior development was apparent. (See Table 3 and fig. 5.) At first glance, the 3–0 stock seemed to be better developed than the 1–2 in most respects. However, the 3–0 stock had poorer balance because of its larger tops and slightly fewer roots than the 1–2. The fact that it had 15 per cent more of total plant weight in the tops than the 1–2 seems an adequate explanation of its inferior survival.

The indicated superiority of 1–2 over 2–0 stock is in full agreement with the results attained 10 years earlier in the tests at Priest River and Wallace, Idaho. In the experiment at Haugan the survival of the 3–0 stock was intermediate between those of 1–2 and 2–0, corresponding to the 2–1 stock in the experiment at Wallace. This suggests that much the same results may be expected from 2–1 and 3–0 stock, although no comparative tests have as yet been made. From the tests actually made, the western white pine age classes rank in this order in ability to survive field planting: 2–2, 1–2, 2–1, or 3–0, 2–0, and 1–1. But when cost of survival is considered, 2–0 stock leads on the less severe planting sites. Of the other possible age classes, 1-year-old trees are too small, and 4-year-old seedlings or 5-year-old transplants are too large for field planting by present methods.

TESTS OF SIZE CLASSES

Strictly speaking, the best size of trees for planting can not be considered independently of the method of planting. Large trees can not be removed from the nursery without the loss of many roots, nor can they be properly planted except by more expensive methods than those ordinarily employed. Also there is a point beyond which the reduction in size of planting stock is not economical. In most places the trees in forest plantations have to fight drought, fungus diseases, rodents, insects, or any of a variety of enemies. Except in very favorable localities, destructive influences limit the reduction in size of planting material and preclude the possibility of success from the sowing of seeds directly in the field (7). The study of the best sizes of trees for planting has thus been restricted within definite limits.

TABLE 5.—*Average tree measurements at the time of planting 1–2 western yellow pines, at Priest River, Idaho*

Size class	Length of root	Length of top	Diameter of stem
	Inches	*Inches*	*Millimeters*
Large	8.2	3.8	3.3
Medium	9.0	3.3	2.4
Small	7.8	2.7	2.0

WESTERN YELLOW PINE

Plantations on flat ground at the Priest River station in the fall of 1913 and spring of 1914 were made with 1–2 western yellow pines from the Savenac Nursery.[6] The trees were sorted into three size

[6] All of the experiments at Priest River station were planned and executed by J. A. Larsen. The work was entirely independent and separate from that at Wallace, Idaho, and Haugan, Mont., but is discussed here as it is within the region and essentially a part of the subject with which this article deals.

classes, the large and well-developed plants being placed in one group, the noticeably small and underdeveloped in another group, and the remaining medium-sized trees in a third group. This grading resulted in 524 large, 978 medium, and 824 small trees. An idea of the relative size of these trees may be obtained from Table 5, which gives the average measurements of 50 mechanically selected representatives of each size class. Planting was done by the so-called prepared-side-hole method. This differs from the slit method principally in that the soil is loosened by a few strokes of the mattock before the hole is made and the tree inserted. The results of this work are shown in Table 6.

TABLE 6.—*Survival and height growth of 1–2 western yellow pines according to size classes* [a]

Size of trees and season of planting	Survival in different years						Height in different years					
	1914	1915	1916	1917	1919	1921	1914	1915	1916	1917	1919	1921
Planted in fall:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Small	52	44	42	41	41	41	4	5	9	12	20	31
Medium	50	44	42	42	42	42	2	6	9	13	18	32
Large	65	60	57	57	57	54	5	7	11	15	24	37
Planted in spring:												
Small	70	51	49	44	44	44	3	4	8	10	18	34
Medium	74	60	58	56	52	52	4	5	9	12	22	33
Large	89	79	79	76	73	73	5	6	12	16	26	38

[a] Plantations made in the fall of 1913 and spring of 1914 on flat land at Priest River, Idaho.

The large trees survived best in both plantations, and following spring planting the medium-sized trees survived better than the small trees. Spring planting resulted in higher survival than fall planting. In both plantings the small and medium-sized trees grew at about equal rates and were surpassed by the large grade. The thrifty appearance of this plantation of large trees after nine years' growth is shown in Figure 6, A. Although this experiment clearly indicates that size of trees greatly influences results, it gives no definite basis for judging the portion of stock that should be rejected before planting in the field.

Greater refinements in grading into size classes were attempted in the spring of 1915, with the view of making it possible to give specific recommendations regarding the proper degree of culling necessary to exclude weak plants. A lot of 4,300 trees were classified into the eight grades illustrated in Figure 7, A, and were planted in the spring of 1915 on a flat and on a southwest aspect.

The relative survival of the trees is indicated in Figure 8. The results on the flat show some tendency toward a reversal of those on the slope, but the order is confused. The uniformly higher survival on the flat is taken as an indication of better soil moisture conditions there than on the slope. The more severe conditions on the slope bring out clearly the inferiority of the lowest grade or smallest 5 per cent of the stock. The smallest 20 per cent of the whole (or lots numbered 1, 2, 3, and 4) remained constantly lower in survival than the 80 per cent of larger plants. Average growth measurements showed that the growth rate increased steadily with the

size of trees planted until, in 1921, the trees from the largest grade were 1 foot taller than those of the smallest grade. The results indicate that although no trees of the grades tested need be rejected

FIG. 6.—Highly satisfactory plantations of 1–2 stock: A, 9-year-old plantation of large-grade western yellow pine stock, trees about 3.5 feet tall, 1922; B, 8-year-old plantation of large-grade western white pine, trees about 2 feet tall, 1922

for planting on favorable sites, about one-fifth of the trees should be culled out before planting the drier slopes.

In May, 1923, about 750 1–2 western yellow pines were lifted at the Savenac Nursery for a test of size classes. After rejecting 5

per cent of these because of poor development or injury, the lot was graded into three classes, large, medium, and small, each consisting of one-third of the total number. Roots of the large plants were pruned to a length of 7 inches, the medium size to 6.5 inches, and

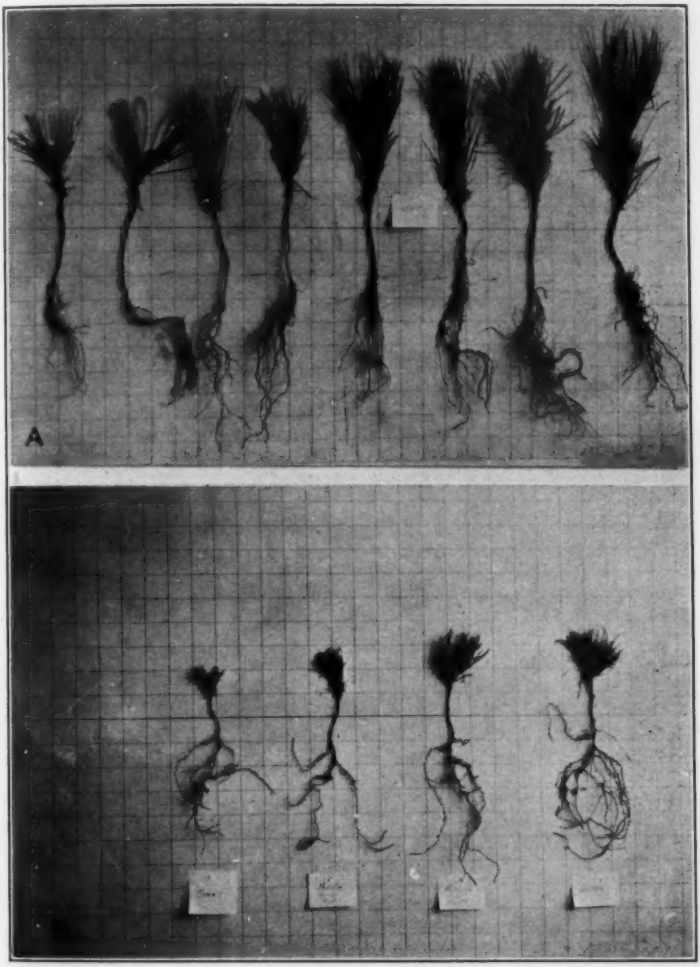

FIG. 7.—Graded sizes of 1-2 planting stock: A, Eight grades of western yellow pine planted in the spring of 1915; B, four grades of western white pine planted in the fall of 1914 and the spring of 1914

the small to 6 inches, in order to maintain as nearly as possible the same balance in the different lots. The figures in Table 7, giving percentage of total plant weight contained in the tops, show this effort to have been successful. The table also shows in detail the difference in size of the plants. Early in 1923 the small grade showed

the largest number of unthrifty plants, the large grade the fewest, and the medium grade an intermediate number, but survival was uniformly high until drought occurred in September. On the seventh day of the month the grades ranked as follows in survival: Large, 90 per cent; medium, 80 per cent; and small, 62 per cent. Each size had the benefit of roots one-half inch longer than those of the next smaller size. Undoubtedly this influenced the results obtained, but as the deeper layers of soil within the root zone did not become dry until September, it does not seem likely that root length alone was responsible for any more of the differences in survival than were the other characteristics shown in Table 7. Mortality during the

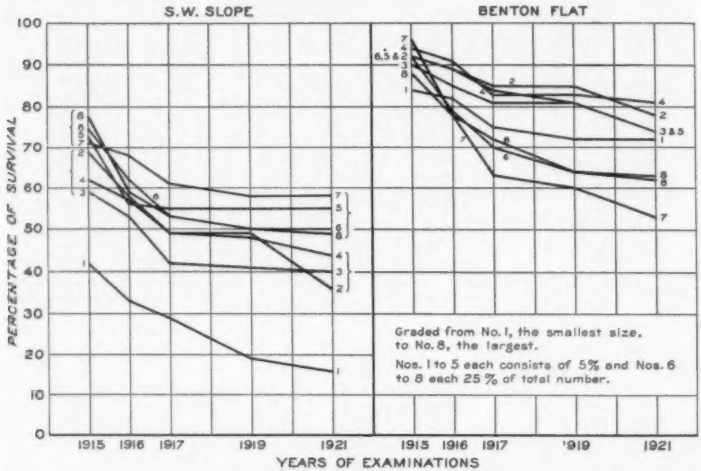
S.W. SLOPE
BENTON FLAT
PERCENTAGE OF SURVIVAL
YEARS OF EXAMINATIONS
1915 1916 1917 1919 1921
Graded from No. 1, the smallest size, to No. 8, the largest.
Nos. 1 to 5 each consists of 5% and Nos. 6 to 8 each 25 % of total number.

FIG. 8.—Size classes, series F, graded 1–2 western yellow pine stock, basis 4,300 plants; plantation of spring of 1915, Priest River Experiment Station, Idaho

second season was also less for the larger sizes. In October, 1924, survival was as follows: Large, 82 per cent; medium, 68 per cent; and small, 45 per cent.

TABLE 7.—*Anatomical characteristics of the root-pruned 1–2 western yellow pine size classes, as determined by average measurement* [a]

Size class	Stem length	Length of needles	Diameter at ground line	Lateral rootlets		Oven-dry weight	Weight in top	Weight in root
				0.5–2 inches	Over 2 inches			
	Inches	*Inches*	*Millimeters*	*Number*	*Number*	*Grams*	*Per cent*	*Per cent*
Large	4.1	3.5	3.6	27.6	15.1	2.6	72	28
Medium	3.4	3.3	3.0	14.8	9.1	1.6	72	28
Small	2.6	2.6	2.2	8.0	4.9	0.8	73	27

[a] Planted in May, 1923, near Haugan, Mont. Averages based on measurements of 60 trees of each size class.

These results were corroborated in 1924 by the results of a plantation containing over 1,175 western yellow pines in each of the size classes—large, medium, and small. In April, the trees were planted on a steep, gravelly south slope where conditions of plant growth were obviously severe. Five examinations during the season showed that survival was constantly highest for the large, intermediate for the medium, and lowest for the small stock, but the differences were not large and by the end of the season less than 15 per cent of the plants were alive in each grade. The combined effect of a severe site and a dry year was the cause of the failure to obtain satisfactory survival. The foregoing results agree with those obtained by Show (*5*) in California, who found that graded sizes of 1–2 western yellow

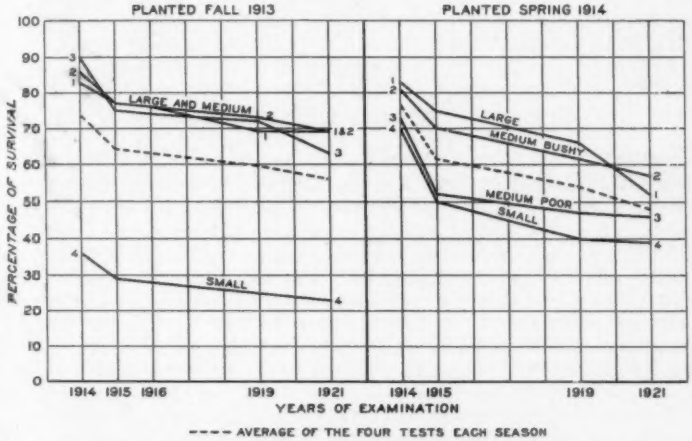

FIG. 9.—Size classes, series A, graded 1-2 western white pine stock, about 400 plants in each test; plantation on Benton Flat, Priest River Experiment Station, Idaho

pine survived as follows in 1916: Large, 50 per cent; medium, 38 per cent; and small, 23 per cent.

WESTERN WHITE PINE

Experiments similar to those with western yellow pine were made with the western white pine at the Priest River station in the fall of 1913 and spring of 1914, using 1–2 stock grown at Savenac Nursery. This time the trees were sorted into four grades: (1) Large stock with large, well-developed roots; (2) medium-sized trees with well-developed roots; (3) medium-sized trees with poor and stringy roots; and (4) small plants. About 40 plants were mechanically selected from each grade for the measurements given in Table 8; representative trees are shown in Figure 7, B. The trends of survival in these plantations are shown in Figure 9.

A quantity of moisture greater than normal was available in the summers of 1914, 1915, and 1916, so that differences in drought hardiness of the various classes do not stand out clearly in all cases. Of the lots planted in the fall the smallest size did very poorly, while the other grades were all much alike. In the fall plantation

survival was on the average higher than in the spring plantation. In the spring plantation the relative order of survival of the grades was constant for six years, showing the tendency toward higher survival of the larger plants. Measurements of total height in 1921 showed that the small class averaged about 4.5 inches shorter than the others, which were all about 22 inches high. (Fig. 6, B.)

TABLE 8.—*Average tree measurements of 1–2 western white pines at the time of planting (fall, 1913, and spring, 1914) at Priest River, Idaho*

Size class	Length of root	Length of top	Diameter of stem
	Inches	*Inches*	*Millimeters*
Large class	8.4	2.7	2.5
Medium with bushy roots	6.5	2.4	2.1
Medium with stringy roots	6.9	2.2	1.9
Small class	6.3	2.0	1.5

PRUNING TOPS TO MAINTAIN BALANCE

The term "balance" as used in speaking of forest-planting material means the relation between the capacity of the root system to absorb moisture and the capacity of the crown or top to transpire moisture, which in turn is a measure of the water use of plants. It is true that other things besides balance influence the economical use of water by plants. Bates (*1*) has shown how the water requirements of trees vary with different species. Numerous external factors influence the water-supplying power of the soil and the evaporating power of the air, thus controlling the flow of water through a plant. But balance, as an attribute of the plant itself, is to a certain extent capable of modification in the nursery.

It is the aim of forest nursery practice to produce plants with tops as small as possible in comparison with the usable portion of the root system. As a rule transplants have much better balance than seedlings that have never had their roots pruned during their period of development, and the usual higher survival of transplants is largely ascribed to their smaller top-root ratio. If differences in survival can correctly be attributed to corresponding differences in balance, as was done with the test of western yellow pine age classes planted in the spring of 1923, it is essential that balance be measured by as precise a method as is practicable. In transpiration tests made in 1917, Bates (*1*) computed the area of leaf surface from needle dimensions and volume displacements, but he recognized the error due to the inclusion of stem volume. Similarly, the weight of wood in stems and roots is a source of error in judging balance from measurements of weight alone. Yet simple comparisons of oven-dry weights are easily made, and the unavoidable error should not destroy the value of the method unless there be great variation in size of the trees compared. Because the method of weight comparison can be applied to representative lots of 100 or more nursery trees at one time, and is easy to use, it is preferred to the "leaf exposure" method.

The balance of trees taken from forest nurseries is almost invariably inferior to that of naturally grown trees of the same age. This is because the root systems penetrate the nursery soil so deeply that

they are seldom removed intact, and also because the especially long roots that did not happen to break off in the soil are pruned off previous to planting in order to prevent them from being doubled up in the planting holes. With hardwoods top pruning is commonly practiced in order to restore the balance that is lost in root pruning. In horticultural practice, because symmetrical tops are desired, the tops of conifers are not pruned, but symmetry is nonessential to forest trees less than 4 years old. Light and severe pruning of needles with both white and yellow pine has been tested in field plantations near Haugan, Mont. Although the results were negative, a few words about the tests may interest those who may have contemplated similar trials.

In preparing 1–2 western yellow pine for planting in April, 1923, certain lots of trees were top pruned. By cutting horizontally with shears, the uppermost portions of needles were removed, leaving only the part of the crown that could not be removed in one cut without injury to the terminal bud. This resulted in plants with about 10 per cent less of their total dry weight in the tops, an improvement in balance that appeared sufficient to increase field survival. No excessive bleeding of sap from the cut ends was observed; the needles promptly sealed their wounds, and the dying of needle tissue progressed only about one-sixteenth inch from the cut ends. Nevertheless, the vitality of the plants must have been reduced in some way by the pruning, because survival was lowered in spite of the improved balance of the trees. Too severe reduction of the organs of photosynthesis is a plausible explanation of the injury. This idea was strengthened by the field observation that the plants that died were principally the smallest ones, which lost the largest proportion of their crowns, and the observation that numerous very thrifty plants were all among the large trees with very slight or no top pruning.

Probably the reduction of the plants' equipment for assimilating food was especially injurious because it was made early in spring, the season of naturally rapid growth. Later pruning might help the plant through the critical period of summer drought without this early interference with vital functions, but of course it could not be considered as a separate operation in practice. The question arose as to whether pruning of tops might be beneficial in connection with late planting. Heavy and light top pruning was tried in both early and late plantations. The lightly pruned trees in the late plantation did best of all, but were not sufficiently superior to the unpruned trees to form evidence in favor of the theory under test. In general, pruning lowered survival.

PROPER LENGTH OF ROOT SYSTEM

The benefits from deep setting of roots on exposed sites have been mentioned by Toumey (*6*). From 1921 to 1924 the following theory along the same line was tested by various experiments: The heavy drought losses in the forest plantations the first season following plantings are largely due to the downward desiccation of the soil during the dry season, the soil often becoming devoid of available moisture beneath the lowermost level reached by the roots. Seedlings arising from natural reproduction immediately extend their roots downward in an attempt to keep ahead of the advancing dry

soil, but planted trees fail to do this with sufficient promptness. Owing to the shock of planting, the downward penetration of roots during the first season is negligible.

A preliminary test was made with 2–0 western white pine in the spring of 1921. Six hundred seedlings were root-pruned at points 8 inches from the ground line and planted on a northwest slope together with 400 seedlings with unpruned roots. Holes were made sufficiently deep to accommodate the roots of each plant without any doubling back. This gave the unpruned lot the advantage of about 1½ inches greater depth of roots. By the end of September, 43 per cent of the unpruned trees and 59 per cent of the pruned trees were dead. Nearly all of the deaths occurred during July and August and were attributed to drought.

With trees planted in the spring of 1923 more thorough tests were made of the influence of root length on survival. Of 1–2 western yellow pines lifted from the nursery in the usual manner, 5 per cent were rejected because of root injury and 2 per cent because of poor development. Many but not all of the trees retained roots 10 inches long, and variation in balance was apparent. Accordingly, as trees were pruned individually at points 4, 6, 8, and 10 inches below the ground line, they were also graded sufficiently so that the larger trees were pruned to the longer and smaller trees to the shorter lengths. This prevented the larger trees from becoming extremely top-heavy. In general, the procedure tended to equalize the balance of the four lots.

The trees were planted in April, 1923, near Haugan, Mont., on a southwest slope having soil of medium quality. During that season this plantation was examined six times at monthly intervals, thus affording opportunity to observe evidences of external causes of injury while they were still fresh. All such causes, other than drought, which appeared to contribute to upthriftiness or death of individual trees were noted and the record of such trees was excluded from further considerations. The number of trees so excluded was not more than 4 per cent of any lot and did not seriously reduce the basis for conclusions.

A study of soil moisture revealed some points of interest. At monthly intervals 10 soil samples were taken to represent the soil at each of two depths, 4 and 10 inches, in different parts of the plantation. As determined in another experiment, the wilting coefficient for western yellow pine is about 3.9 per cent of the weight of dry soil. Applying this figure to the results obtained from field samples permits their expression in terms of moisture available to western yellow pine. (See Table 9.) On July 3 the soil within reach of the trees appeared quite uniformly moist, whereas a month later the top layers had dried out until the soil at the 4-inch level contained only about one-third the amount of moisture available at the 10-inch level. The rains of August then added nearly enough moisture to the upper layers to offset further losses, but did not penetrate as deeply as 10 inches. However, the continued dampness of the soil about 10 inches from the surface for a month after the upper soil was dry had a perceptible effect on the trees.

TABLE 9.—*Soil-moisture determinations at 4 and 10 inch depths*

Date	Moisture at 4-inch depth		Moisture at 10-inch depth	
	Total	Available	Total	Available
	Per cent	*Per cent*	*Per cent*	*Per cent*
July 3	18.9	15.0	18.6	14.7
August 3	7.4	3.5	15.5	11.6
September 3	6.6	2.7	6.2	2.3
October 3	6.3	2.4	5.9	2.0

Soil-moisture losses were greater than gains during the summer, but the precipitation for the season was above normal in amount each month until September, and until then the survival of all lots of trees remained high. A 20-day rainless period accompanied by high

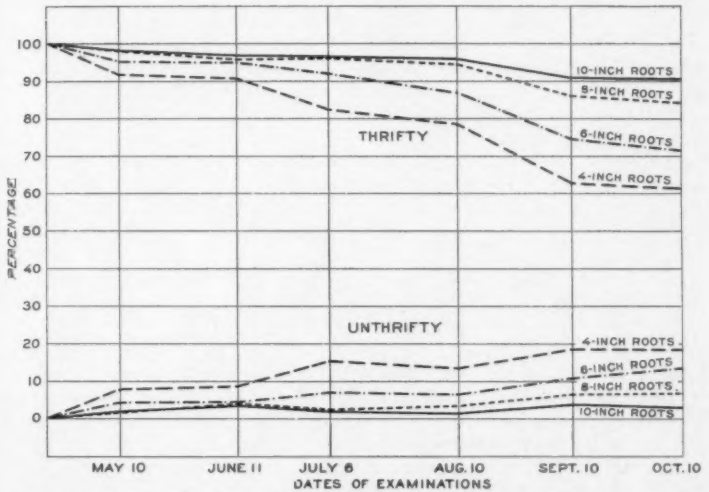

FIG. 10.—Root-length test: Relative thrift during 1923 in the 1-2 western yellow pine plantation of the spring of 1923; stock graded to preserve balance; roots measured and pruned individually; plants affected by causes other than dryness are not considered; southwest aspect

temperatures started on August 27, causing an acceleration of the death rate in plantations. Drought hardiness increased with the length of roots. At the end of the season figures of the percentage of survival for the different root-length classes were as follows: 4 inch, 80 per cent; 6-inch, 85 per cent; 8-inch, 91 per cent; and 10-inch, 94 per cent. Although these percentages, owing to the moist season, are all unusually high, they serve the purpose of the experiment in showing clearly and consistently the influence of length of roots. From observations made at intervals figures were compiled showing the relative number of thrifty and unthrifty trees in percentage of the total number planted. These figures, plotted in Figure 10, show clearly that throughout the season the trees with short roots were less thrifty than those with longer roots.

A year later the relative survival was the same as at the end of the first season, the differences amounting to 6 or 7 per cent for each 2-inch increase of root length. Measurements of current stem growth

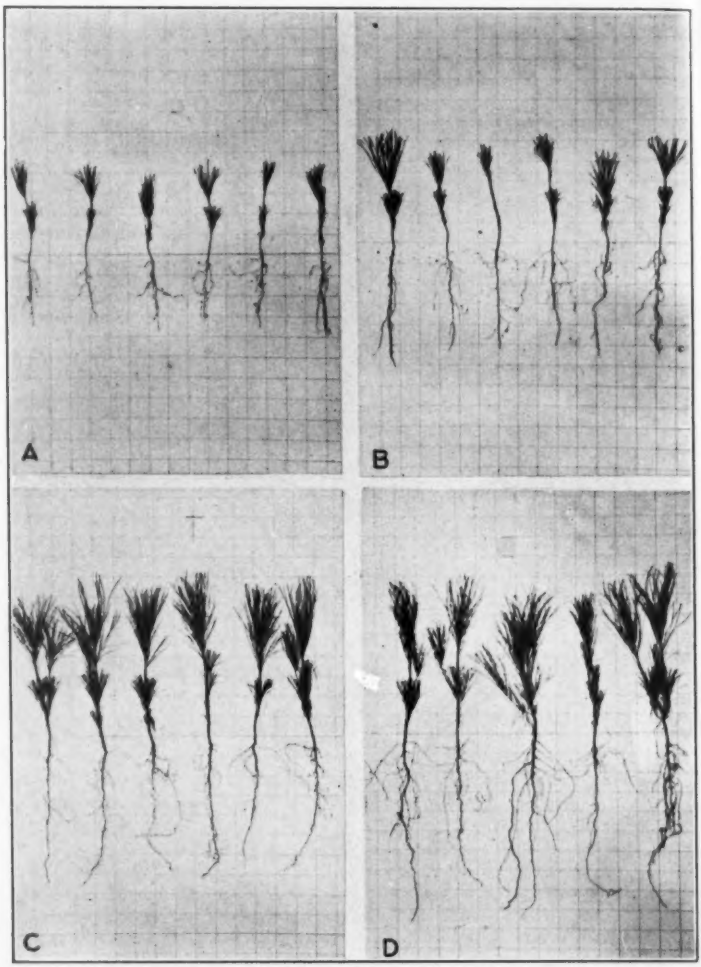

FIG. 11.—Western white pine root lengths: A, 4-inch class; B, 6-inch; C, 8-inch; and D, 10-inch

showed small but consistent increases in growth for the longer root lengths.

In 1923 a very similar experiment was made with 3–0 western white pines planted on a northwest slope. The trees are illustrated in Figure 11. The results were much like those attained with western yellow pine.

In weighing the results, the probable effect of the preliminary grading that tended to equalize the balance should be considered. Had the grading been omitted the long-rooted trees would have been less top-heavy and the short-rooted trees more so. Differences in survival of the various root-length classes might well have been still greater had it not been for the preliminary grading.

In sowings made in April, 1924, it was considered that in actual practice in pruning roots to certain lengths thorough grading will rarely precede the pruning of roots, and therefore no attention was paid to size and development of trees. More than 1,250 1–2 western yellow pines from each of three root-length classes, 6, 8, and 10 inches, were planted on a gravelly south slope presenting severe conditions for plant life. By the end of June the soil had become quite dry and but 63 per cent of those with 6-inch roots, 76 per cent of those with 8-inch roots, and 83 per cent of those with 10-inch roots were alive. By the end of July, the driest month, survival was as follows: Those with 6-inch roots, 14 per cent; 8-inch roots, 27 per cent; and 10-inch roots, 36 per cent.

A post-mortem examination of numerous trees indicated that the difficulty of planting properly in a loose gravelly soil and on a brushy site had resulted in a loss of the desired depth of root penetration at the time the trees were set out. Owing to slight root curvature, doubling back, inclination, or depth of setting, the average penetration was about 0.5 inch less than was intended, the different lots being affected differently. The 6-inch roots had lost about one-quarter inch, and for each additional 2 inches of root length, the loss of depth increased about a quarter inch. In other words, the trees with 6-inch roots actually penetrated 5.75 inches, the trees with 8-inch roots, 7.5 inches, and those with 10-inch roots, 9.25 inches, making the interval 1.75, rather than 2 inches. This condition did not affect the applicability of the results, because a better quality of planting could not be expected on such sites. However, it served to show that low survival on severe sites may be due not only to direct action of the site factors but also to the indirect action of the site in decreasing the quality of planting. A similar observation was made in California by Show (*5*), who found that quality of planting decreased with the increase in density of brush cover.

The four experiments described above indicate consistently that, within the limits tested, increases in the length of roots planted result in corresponding increases in survival.

SUMMARY

The results of the experiments with western yellow and western white pine showed that, other factors being equal, large stock survived better than small stock, that transplants are usually preferable to seedlings, that stock with roots 8 inches long or longer succeed better than stock with shorter roots, and that a low top-root ratio indicates better planting stock than a high ratio.

A higher proportional survival was found in the older age classes of both species. In one planting upon northwest, west, and southwest slopes, 1–2 stock of western yellow pine grew most rapidly from the start and also appeared the most economical from the standpoint

of the cost per unit of surviving trees. In another test, comparing survival of two age classes, 2–1 stock did better than 1–2, but 1–2 still remained the more economical. In one western white-pine planting 1–2 stock ranked superior to 2–0. In another planting of white pine in which 2–2 stock was used, this stock had the highest survival, with 1–2, 2–1, 2–0, and 1–1, in descending order. Upon the basis of cost per unit of survival 2–0 white-pine stock appeared most economical on moderate sites, but on the more severe sites 1–2 stock, or possibly 2–2, proved the least expensive.

In several experiments with size classes large stock of western yellow pine survived better than small stock on severe sites. Medium-sized stock appeared best on favorable sites. When western white-pine stock graded into four size classes was planted, only the smallest class resulted in poor survival.

When 1–2 western yellow-pine stock was root pruned to furnish root lengths of 10, 8, 6, and 4 inches, highest survival attended the stock with 10-inch roots. The survival declined quite uniformly with the decrease in root lengths regardless of whether the stock has been sorted into size classes so that the root pruning was in proportion to the total size of the stock or not. Roots 8 inches or longer seemed best.

In general the season of planting appears to have slight effect upon survival.

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TWO NEW ALEYRODID (CITRUS) PESTS FROM INDIA AND THE SOUTH PACIFIC [1]

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This paper records two white-fly pests that are apparently very serious enemies of citrus in their respective countries. Great care should be taken to see that they are never introduced into other citrus-growing regions of the world, where they would undoubtedly prove to be citrus enemies of first rank.

While the following species of white-fly undoubtedly falls into Cockerell's genus Dialeurodes, a new subgenus must be erected for its inclusion. It differs greatly from the other members of the genus in its extremely elongate shape.

FIG. 1.—Citrus leaf infested with *Dialeurodes* (*Dialeurolonga*) *elongata* and *Aleuromigda* sp. Greatly enlarged

Dialeurolonga, new subgenus.

Pupa case very elongate, more or less asymmetrical, yellowish, shallow corrugations or striations on the submarginal area with a row of papillalike pores present; dorsal disk without pores and with no development of rhachis; thoracic tracheal folds distinct, ending on margin in a pore; vasiform orifice rather elongate, the caudal margin toothed.

Type of subgenus.—*Dialeurodes* (*Dialeurolonga*) *elongata* Dozier

Dialeurodes (Dialeurolonga) elongata, new species.

Easily distinguished from all other Dialeurodes by its elongate shape. (Fig. 1.) At a superficial glance it reminds one of *Bemisia giffardi.*

[1] Received for publication Apr. 7, 1928, issued August, 1928.

Pupa case (figs. 2 and 3) yellowish white, lying closely adpressed to the leaf surface; scattered indiscriminately on lower surface and greatly resembling a young Lecanium scale; without any kind of wax secretion.

Length 1.46 mm., greatest width 0.670 mm. Shape very elongate-elliptical but distinctly unsymmetrical in outline. Thoracic and caudal tracheal folds prominent, terminating in distinct pores. The entire surface apparently granulated in balsam mounts; the submarginal area set off by corrugations or striations, more whitish or transparent in color; a row of inconspicuous papillalike pores follows around the submarginal border; vasiform orifice rather elongate, the caudal margin toothed; the operculum similar in outline.

In balsam slide-mounted specimens, the color of the pupa case is a transparent yellowish white with two irregular patches of orange pigment on disk on each side of the abdominal region, and this orange coloring is very characteristic.

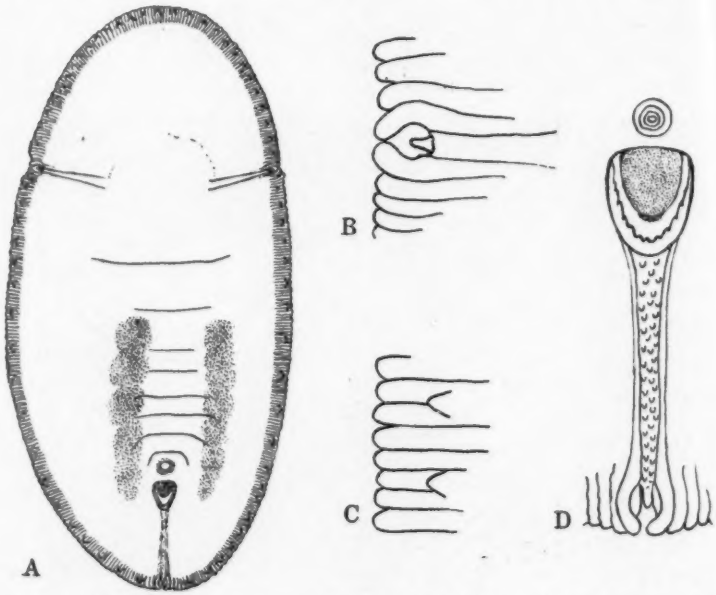

FIG. 2.—*Dialeurodes* (*Dialeurolonga*) *elongata:* A, Pupa case; B, thoracic tracheal pore; C, margin of pupa case; D, vasiform orifice and caudal pore

Described from abundant pupa-case material, slide mounted in Canada balsam and on citrus leaves, collected by M. Afzal Husain at Lyallpur, Punjab, India, March 29, 1926, No. 308.

Cotype slide-mounted material of the above-described new species is deposited in the collections of the United States National Museum, the British Museum, the California Citrus Experiment Station, the Florida State Plant Board, and the private collections of the author and of the Japanese authority on this family, S. I. Kuwana.

ALEUROPLATUS (ORCHAMUS) SAMOANUS LAING

This species on account of the vasiform orifice being armed with teeth falls at once into the subgenus Orchamus, and is closely allied to *Aleuroplatus mammaeferus* Q. & B. It is less elliptical than that

species, the marginal pores are different, the thoracic comb is more depressed, and the teeth are distinctly longer.

Pupa case (fig. 4) 0.828 mm. in length; greatest width 0.584 mm. Shape oval, constricted across the cephalic portion at the thoracic folds. Dorsal sutures very indistinct. The margin with very indistinct shallow rounded teeth; supplied with a pair of extremely minute setae on anterior margin and another pair on posterior margin that might easily be overlooked. Just within the margin all around is a row of prominent pores that at first glance under the high power of the microscope give the impression of being very toothlike. A pair of nonprominent spines or setae present on disk of dorsum. The marginal thoracic

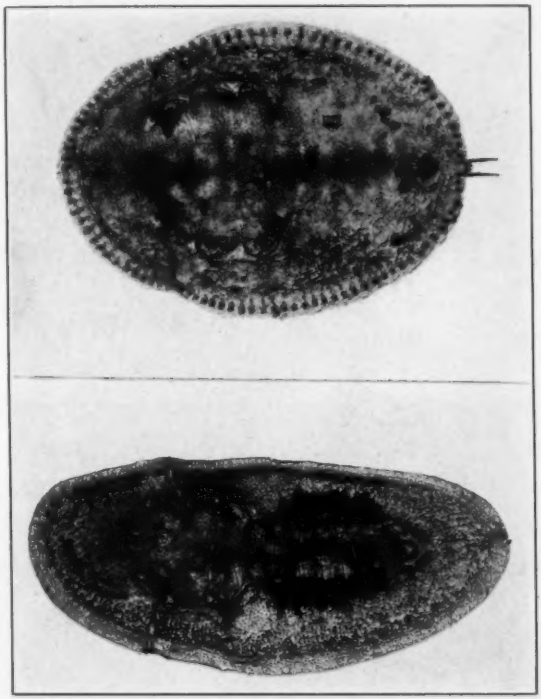

FIG. 3.—Photomicrographs of the pupa cases of *Dialeurodes elongata* and *Aleuroplatus samoanus*

comb distinctly depressed, very prominent, formed by long, narrow teeth, about 11 in number; the caudal fold is armed with a similar prominent comb composed of 9 teeth, and on each side of this comb is a long, distinct marginal seta. Vasiform orifice broadly rounded, the lateral caudal margins armed with distinct teeth or folds. Color of case a transparent dirty or yellowish white.

On the leaf the pupa case appears slightly elevated, surrounded with a very broad, flattened, yellowish white waxy secretion which varies in width and irregularity of outline.

Adults unknown.

The above description was made from abundant pupa-case material on leaves of citron (*Citrus medica*), collected by the late F. L. Washburn in his expedition to the Marquesas Islands in the South Pacific in 1926. This material is preserved in two vials of

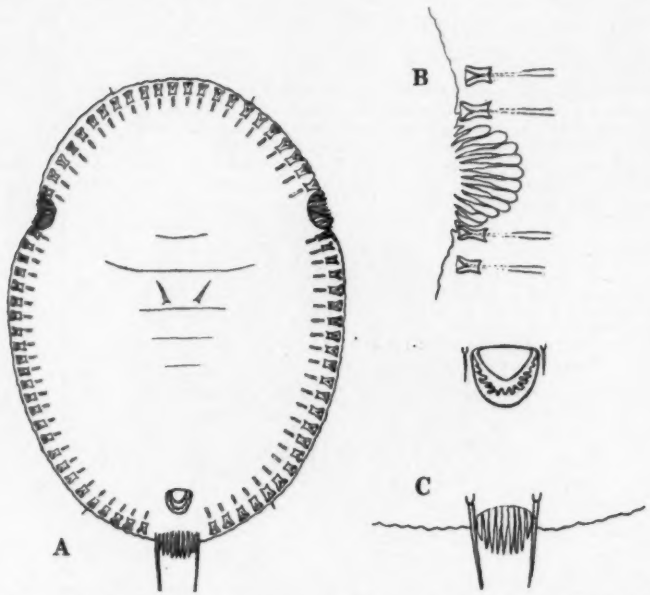

FIG. 4.—*Aleuroplatus* (*Orchamus*) *samoanus*: A, Pupa case; B, thoracic tracheal comb and wax pores; C, vasiform orifice and caudal comb

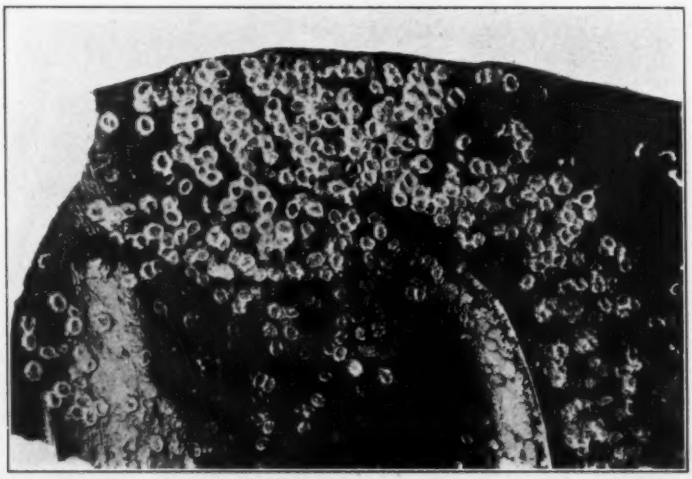

FIG. 5.—Citron leaf heavily infested with the white fly, *Aleuroplatus samoanus* L. Enlarged. Photograph made from formalin-preserved material

formalin, the cork of one of which is marked "H" and the other "T 8 citron." Clarence E. Mickel, who sent the writer this material for study, has been able to locate some notes left by Washburn that undoubtedly refer to this material. "I left San Francisco June, 1926, and arrived at Tahiti on June 26. I employed my time collecting in the vicinity of Ventura, 13 kilometers from Papeete, avoiding, as far as possible, duplication of the collection made on this island two years previously." He listed a few aleurodids among the material taken in this vicinity. "Hikueru was our next stop. Here I collected for eight days. The insect fauna on Hikueru was found to be practically identical to that at the atols previously visited." While no mention is made of aleyrodids being taken on Hikueru, the "H" on the vial of material collected on the first trip in 1923 most probably refers to this island as Washburn states at the end of these notes that "H" equals Hikueru, collected in August.

The infested leaves in both of the vials are undoubtedly *Citrus* sp. and are extremely heavily infested. *Aleuroplatus samoanus* was described (Insects of Samoa, Pt. II, British Museum, 1927) from thickly coated leaves of cultivated Croton on Upolu Island, Apia, IV, 1925, and the material here discussed represents without much question that species.

AN APPARATUS FOR OBTAINING MEASURED AREAS OF SPRAYED FOLIAGE FOR CHEMICAL ANALYSES[1]

By JOSEPH M. GINSBURG[2]

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INTRODUCTION

In studying adhesion of insecticides and fungicides to foliage it is often necessary to determine the leaf area covered by the spray material before chemical analyses are made. For this purpose leaves are collected and the area of each one is determined separately. The measurements are made either from the fresh leaves directly or from blue prints, usually by the aid of a planimeter. Anyone who has had an opportunity to measure foliage by this method will admit that the work is rather tedious and time consuming, especially when a large number of leaves are to be measured. Besides, some of the spray material is bound to be shaken from the leaves during the process of measuring, particularly when the leaves are allowed to become dry before they are measured, thus providing a source for error in the subsequent chemical analyses. Again, experimental orchards are not always situated close to laboratory facilities and one or two days may often elapse from the time the leaves are cut until the measurements are taken, with the result that the exact area can not be obtained.

While engaged in an investigation of stickers and dilutents in arsenic-sulphur sprays and dusts, the writer tested out several methods for measuring the foliage surface in the field at the same time that the leaves are collected from the trees. After several efforts, the following apparatus was devised which gave satisfactory results.

DESCRIPTION OF APPARATUS

The apparatus (fig. 1) consists of a steel base (*a*) from which is extended an arm (*b*) ending in a hollow sleeve (*c*). This entire part was cut out from one piece of solid steel. In the center of the base is a round opening (*d*), 1¾ inches in diameter, into which steel dies (*i*) of various sizes can be fitted. Into the sleeve is inserted a plunger (*e*) around which winds a retarding spring (*f*). The lower end of the plunger is provided with an opening into which round cutters (*h*) of various diameters can be inserted and tightened with a flathead screw which passes through the plunger and grips the narrow end (*g*) of the cutter but does touch the inner wall of the sleeve. This arrangement allows free movement of the plunger in the sleeve. The cutter is partially hollowed inside and tapers to a very fine, sharp edge so that when the cap of the plunger is pushed down it fits snugly into the die. This arrangement is absolutely necessary in order to obtain a clean cut of the leaf tissue and to cause the cut area to fall out promptly from the die without touching the upper surface of the cutter.

[1] Received for publication Apr. 26, 1928; issued August, 1928. Paper of the Journal Series, New Jersey Agricultural Experiment Station, Department of Entomology.

[2] The author wishes to express his indebtedness to Dr. Thomas J. Headlee for helpful suggestions given during the construction of the apparatus.

The leaf is inserted between the die and the cutter and the cap of the plunger forced with the left hand, the arm of the apparatus being held in the right hand, until it hits the die. A round area of leaf tissue is thus cut out which automatically falls into a paper bag, or any other suitable container, attached to the base of the apparatus. During this operation the surface of the leaf is not touched by either the die or the cutter, except at the edges where the cut is made, and no loss of spray material occurs. As soon as the plunger is released the retarding spring causes it to move upward to its original position ready for another cutting. Each time the plunger moves upward the disk of the cutter raises a lever (*k*) extended from a small, three-figure counter (*j*) attached to the base of the apparatus. By this device every leaf-cut is automatically registered on the small counter

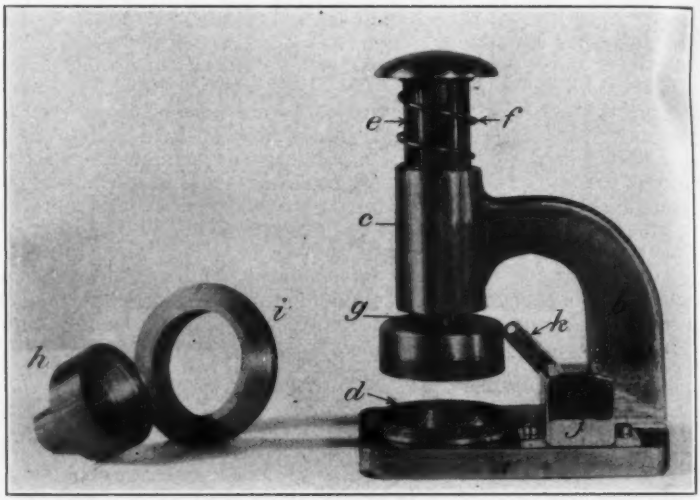

FIG 1.—Apparatus with automatic counter: *a*, Steel base; *b*, plunger arm; *c*, hollow sleeve; *d*, round opening to hold dies; *e*, plunger; *f*, retarding spring; *g*, narrow end of cutter; *h*, cutter; *i*, die; *j*, automatic counter; and *k*, lever connecting puncher with counter

and the total leaf surface collected can be calculated by multiplying the number of leaf areas cut (read from the counter) by the area of the cutter used.

As may be seen from the photograph of the apparatus, the cutter, and of course the die, can be readily removed from the apparatus and others of any desired size inserted, The cutters used in this apparatus were of two sizes. The larger size has a diameter of 1.5 inches and cuts a leaf area of 1.78 square inches, while the smaller one is only 1 inch in diameter and cuts a leaf area of 0.79 square inch. By the aid of this apparatus any desired total leaf surface can be obtained for chemical analysis by merely calculating the number of round leaf areas required to make up that surface.

CHEMICAL ANALYSES

The question came up as to whether or not the amount of chemicals recovered from the round areas fairly represents the amount on the entire leaves. To determine this point several samples of foliage

from two sprayed apple trees were collected and analyzed for arsenic and sulphur. The apple trees had been sprayed in the earlier part of the summer with spray mixtures containing 8 pounds of sulphur, 1½ pounds of lead arsenate, and various porportions of ferric oxide. The samples were collected during August and September. While cutting leaf samples with the apparatus, care was taken to obtain areas near the edges as well as from the central parts of leaves in order to secure representative samples.

The leaves were weighed, dried to constant weight at 65° C., ground to a fine powder, and stored in tightly stoppered glass bottles for chemical analyses. The arsenic analysis was carried out by the modified Gutzeit method [3] while the sulphur was determined gravimetrically according to the Official Methods,[4] the fusion being made in an electrically heated muffle furnace. Averages of duplicate determinations, calculated in milligrams of As_2O_3 and SO_3 per gram of green leaves, are given in Table 1.

TABLE 1.—*Amounts of As_2O_3 and SO_3 found in apple foliage when determinations were made on entire leaves and on round areas cut with the apparatus*

Leaf sample No.	Date collected	Milligrams of As_2O_3 per gram of green foliage in—		Milligrams of SO_3 per gram of green foliage in—	
		Entire leaves	Round areas	Entire leaves	Round areas
30	Aug. 25, 1927	0.140	0.149	2.80	2.50
31	Sept. 3, 1927	.125	.129	3.10	3.40
32	Aug. 10, 1927	.073	.070	Not determined	
33	Sept. 7, 1927	.070	.071	3.00	3.10

A comparison of the results secured from the two sets of samples does not reveal any appreciable differences between the quantities of arsenic or of sulphur found in the apple leaves. It appears therefore, that the apparatus herein described can be satisfactorily used in obtaining measured leaf areas for chemical analyses. By the aid of this apparatus the time and work required for planimeter measurements may be eliminated.

[3] SCOTT, W. W., STANDARD METHODS OF CHEMICAL ANALYSIS. p. 40. New York. 1917.
[4] ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS AS COMPILED BY THE COMMITTEE ON REVISION OF METHODS. REVISED TO NOV. 1, 1919. 417 p., illus. Washington, D. C. 1920.

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THE TOUGHNESS OF COTTON BOLLS IN RELATION TO AGE AND NUTRIENT SUPPLY AS MEASURED BY PRESSURE TESTS[1]

By GEORGE M. ARMSTRONG

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INTRODUCTION

The fruiting responses of the cotton plant as influenced by several factors have been under investigation since 1924. Progressive changes in boll development have received attention, particularly the stage of maturation as determined by resistance to puncture.[2] This paper presents chiefly the results of the pressure tests on cotton bolls, with some data on boll size and wall thickness as associated with the stage of maturation. Data from pressure tests representing stages in the development of cotton fruits assume a somewhat different aspect from the results obtained with edible fruits, since with maturity the cotton boll dries and cracks, exposing a mass of lint. The boll period, or the number of days from the appearance of the bloom to the open boll, is known to be appreciably lengthened or shortened by seasonal conditions. These conditions undoubtedly affect both the physical and chemical processes involved in development. It was thought that the progress of some of these changes could be determined by a pressure test on bolls of known ages developed at different periods in the growth of the plant. Results were obtained during three seasons.

General observations have shown that cotton bolls are not seriously damaged by the cotton-boll weevil in their later stages of development, and it was thought that this resistance to attack with increasing age might be correlated with thickness and toughness of the boll wall.

Mechanical appliances for studying the maturity of fruits and vegetables have been used by a number of workers in the past few years, the idea being that alterations in the tissues with increasing maturity cause changes in the resistance to penetration. Lewis, Murneek, and Cate (*8*),[3] using a pressure tester on pears, state that the idea for the apparatus they describe was obtained from O. M. Morris, of the Washington Agricultural Experiment Station. According to the information available to the writer, Morris was the first to use a pressure tester on fruits. There have been other pressure tests (*5*, *15*) on pears. A pressure test on apples has also been used by a number of workers (*9*, *10*, *11*, *14*, *16*).

One of the most accurate instruments for mechanical puncture tests is a modified Joly balance, which has been used by Hawkins and Harvey (*6*) on potatoes, by Rosenbaum and Sando (*17*) on

[1] Received for publication Apr. 9, 1928; issued August, 1928. The tests herein reported were conducted at the Pee Dee Experiment Station, Florence, S. C.

[2] Pressure tests on a total of 190 bolls of two varieties were made by C. A. Ludwig, at Clemson College, in 1923. The results and a picture of the apparatus were kindly furnished the writer before this work was begun; however, a different type of apparatus was developed for the present investigation.

[3] Reference is made by number (italic) to "Literature cited," p. 1024.

tomatoes, by Hawkins and Sando (*7*), and by Willaman, Pervier, and Triebold (*19*) on small fruits.

The puncture method to determine the toughness of the pericarp of sweet corn as related to maturity and other factors has been used by Rudnick and Bakke (*18*), by Culpepper and Magoon (*1*, *2*), and by Magoon and Culpepper (*12*). All of these investigators report a progressive increase in the resistance of the pericarp to puncture with increasing maturity of the corn. The developing cotton boll, however, does not show a continuously increasing resistance to puncture as does the corn grain, for the boll may at times offer greater resistance to penetration at 21 or 27 days of age than at 41 days of age.

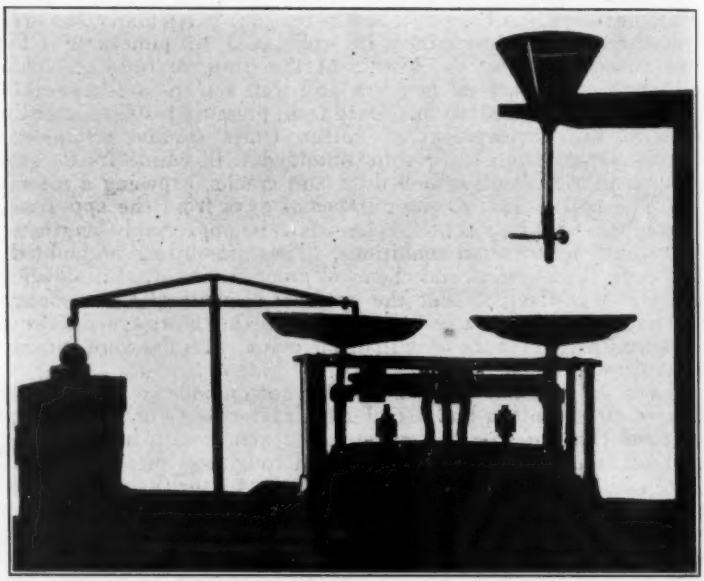

FIG. 1.—Apparatus used in 1924 for pressure tests on cotton bolls

METHOD OF PROCEDURE

The bolls were secured in 1924 from rows in the general cotton variety test. Tags bearing the date of appearance were attached to the white blossoms on plants of an outside row of each of eight varieties, and the bolls used for the pressure test were taken from these plants. In 1925 and 1926 treatment with a fertilizer relatively high in nitrogen was given to one of two adjoining half-acre plots, while a fertilizer relatively low in nitrogen was applied to the other plot. Two rows in each plot were selected for the tagging of blossoms and the subsequent removal of bolls.

Only a few bolls were taken from each plant, and these relatively late in the season, so that there was not the stimulation of vegetative growth which usually occurs when several bolls per plant are removed early in the season.

Samples of 10 bolls each were collected and puncture tests made immediately. The same sewing-machine needle, with the end so ground that a ball point penetrated the tissue, was used throughout the tests. The apparatus essentially as represented in Figure 1 was used in the tests of 1924. In actual operation it was found most convenient to place the boll in the pan, reverse the lever, and have the fixed end at the point where the needle and boll are represented. Sand from the funnel was run onto the pan of the torsion balance until the indicator made a quick movement, which showed the plunge of the needle into the tissue. The sand was then weighed. The apparatus illustrated in Figure 2 was used in 1926. The same pressure tester was used in 1925, but a slightly different arrangement did not permit quite the ease of operation as in 1926. The instrument was adapted from that illustrated by Culpepper and Magoon (*1*).

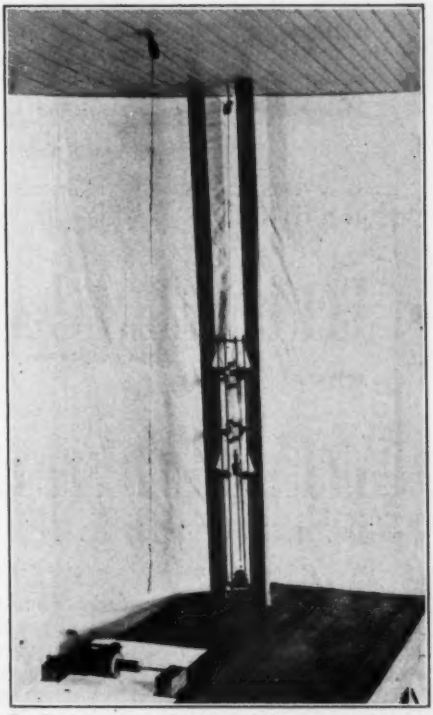

FIG. 2.—Apparatus used in 1925 and 1926 for pressure tests on cotton bolls

The wall of an immature cotton boll consists of three more or less distinct layers, a thin epidermis, a thicker spongy layer, and an inside fibrous-membranous layer. Pressure applied to the needle causes first a plunge as the epidermis is penetrated and then a second plunge as the inner layer is pierced. In cases where the plunge was not distinct, the test was repeated. Both pressures were recorded in 1924, but only the pressure necessary to penetrate the inner layer was recorded in 1925 and 1926. It appeared that the relative development of this layer was a better index of the stages leading to maturation, and it was certainly the only anatomical feature of the boll wall that would seem to offer sufficient resistance to boll weevil penetration to be of protective value. Each locule was punctured at two points on a line following the greatest circumference of the boll at right angles to the sutures. The side of the boll exposed to the sun is generally more highly colored than the unexposed side, and it was noted that the exposed side would frequently offer more resistance to puncture than the unexposed side. Since the bolls usually have from three to five locules, there were 6 to 10 tests per boll which made 62 to 98 tests for a 10-boll sample. The average of a 10-boll sample is used in all comparisons.

RESULTS OF PUNCTURE TESTS, 1924

Two series of bolls from eight varieties were tested at 27, 34, and 41 days of age, one series having developed earlier in the season than the other.

An examination of Table 1 and Figure 3 shows that there was a general tendency toward an increase in boll toughness with age in bolls of the early series tested between August 11 and September 5, inclusive. This tendency was not marked in the Mexican Big Boll and Wannamaker Cleveland varieties.

Bolls of the later series showed no such regularity. In some varieties there was an increase in toughness with age for this series, while with others the reverse was true.

A comparison of the 27-day bolls in the two series shows the bolls of the late series to be tougher in every instance, and the difference in toughness is often much greater than that between bolls of 27

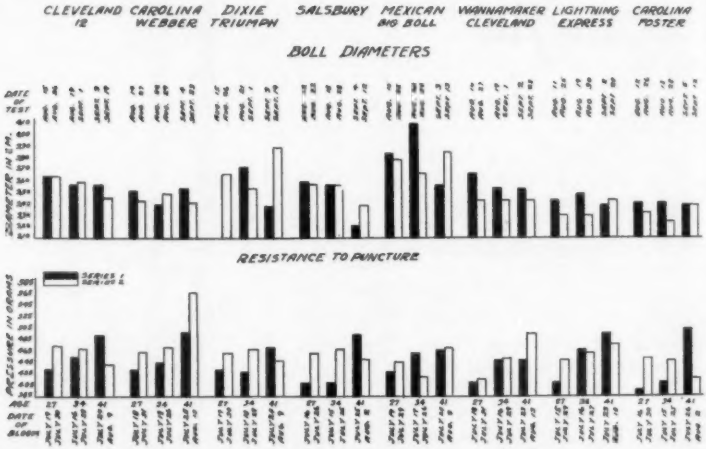

FIG. 3.—Diameter and resistance to puncture of bolls from eight varieties of cotton, 1924

and 34 days of a single series. The same is true in general of the 34-day bolls of the two series. Thus it is seen that the age of the boll alone is not the chief factor in determining its toughness, or its resistance to puncture. The general trend of increase in toughness with age in the first series indicated that all varieties responded to the complex of seasonal conditions in much the same way. The variations in the second series seem to indicate either a distinct varietal response or an effect of conditions at or immediately preceding the time of the test. Bolls of the same age from all varieties were not tested on the same day in either the first series, with its more or less regularity in toughness of wall, or on the same day in the second series, with its irregularity in toughness of wall, which would indicate that the day of test is not the chief factor. Nevertheless the occurrence of such rather high figures as those for Carolina Webber and Wannamaker Cleveland on the last test of September 23, together with several such instances in 1925 and 1926, indicates that the seasonal conditions about the time of the test are sometimes of importance.

TABLE 1.—*Results of an average puncture test upon 10 cotton bolls of 8 varieties at 27, 34, and 41 days of age, 1924*

Series No.	Date of bloom	Date of test	Boll diameter	Age	Pressure [a]	Date of bloom	Date of test	Boll diameter	Age	Pressure [a]
	Salsbury					Cleveland 12				
			Cm.	*Days*	*Grams*			*Cm.*	*Days*	*Grams*
1	July 16	Aug. 12	3.58	27	406	July 19	Aug. 15	3.63	27	[b] 439±5.1
	July 15	Aug. 18	3.56	34	407	July 16	Aug. 19	3.56	34	449±4.8
	July 25	Sept. 4	3.20	41	495	July 24	Sept. 3	3.56	41	495±5.1
2	July 26	Aug. 22	3.56	27	463	July 30	Aug. 26	3.63	27	479
	July 25	Aug. 28	3.56	34	468	July 29	Sept. 1	3.58	34	471
	Aug. 2	Sept. 12	3.38	41	450	Aug. 9	Sept. 19	3.45	41	442
	Mexican Big Boll					Wannamaker Cleveland				
1	July 19	Aug. 15	3.84	27	427	July 18	Aug. 14	3.66	27	407
	July 17	Aug. 20	4.09	34	462	July 16	Aug. 19	3.53	34	451
	July 24	Sept. 3	3.56	41	466	July 23	Sept. 2	3.51	41	451
2	July 29	Aug. 25	3.78	27	445	July 31	Aug. 27	3.43	27	416
	July 26	Aug. 29	3.66	34	423	July 29	Sept. 1	3.43	34	456
	Aug. 3	Sept. 13	3.86	41	467	Aug. 13	Sept. 23	3.43	41	495
	Lightning Express					Carolina Foster				
1	July 15	Aug. 11	3.43	27	409	July 16	Aug. 12	3.40	27	396
	July 16	Aug. 19	3.48	34	466	July 15	Aug. 18	3.40	34	411
	July 23	Sept. 2	3.38	41	496	July 26	Sept. 5	3.38	41	504
2	July 29	Aug. 25	3.30	27	449	July 30	Aug. 26	3.33	27	453
	July 27	Aug. 30	3.30	34	462	July 25	Aug. 28	3.25	34	450
	Aug. 10	Sept. 20	3.43	41	470	Aug. 2	Sept. 12	3.38	41	418
	Carolina Webber					Dixie Triumph				
1	July 18	Aug. 14	3.51	27	[b] 431±4.9	July 19	Aug. 15	.....	27	[b] 433±4.6
	July 19	Aug. 22	3.38	34	445±4.3	July 18	Aug. 21	3.71	34	431±5.0
	July 25	Sept. 4	3.53	41	497±5.8	July 24	Sept. 3	3.38	41	470±5.1
2	July 31	Aug. 27	3.43	27	464	July 30	Aug. 26	3.56	27	462
	July 26	Aug. 29	3.48	34	473	July 29	Sept. 1	3.53	34	466
	Aug. 13	Sept. 23	3.40	41	566	Aug. 9	Sept. 19	3.89	41	448

[a] Each figure for pressure represents an average of 62 to 98 punctures of innermost boll wall.
[b] Standard error.

Differences in rate of maturity may also be of importance in causing such high figures as those mentioned, since bolls will sometimes open when 40 to 45 days of age early in the season, whereas 60 to 70 days are required later.

Some varietal differences can be seen also in the eight varieties tested in 1924, though no one variety shows the least or greatest resistance to puncture in the bolls of all ages.

RESULTS OF PUNCTURE TESTS, 1925

The test in 1925 was confined to three varieties, Dixie Triumph, Cleveland 12, and Carolina Webber. The plants were grown under two conditions of fertility, namely, high nitrogen and low nitrogen, on adjoining one-half acre plots. One plot received four equal applications of nitrate of soda at a total rate of 400 pounds an acre; the other plot received one application at a rate of 100 pounds an acre. There was also a difference in the total fertilizer applied, the high-nitrogen plot receiving 849 pounds of an 8–4–3 and the low-nitrogen plot 196 pounds of the same mixture.

Marked responses to additions of nitrogen are obtained in field plots, since the soils of this region are very deficient in this element. The two treatments thus produced very appreciable differences in plant response as shown by general vigor, green color, height, and number of matured bolls per plant.

The gross features in plant response not only were affected, but the results given in Table 2 and Figures 4 and 5 seemingly indicate appreciable differences in toughness of the boll wall. A few exceptions to the general trend will be noted, yet these might be expected since a 10-boll sample is not considered a fully representative one. It is believed that the use of approximately 65 to 100 carefully performed

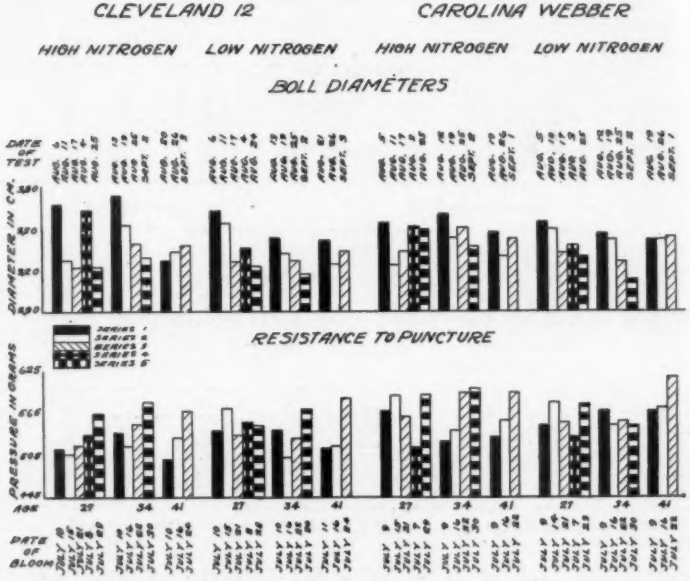

FIG. 4.—Diameter and resistance to puncture, Cleveland 12 and Carolina Webber cotton bolls, 1925

puncture tests on 10 bolls gives a fairly reliable index for the sample studied as shown by the standard error calculations,[4] but the sample was not always fully representative of the field, as indicated by boll diameter measurements which were also taken. Another factor that undoubtedly leads to variations, at least in the older bolls, is the difference in the rate of maturity, which has been previously mentioned. There are also differences in the earliness of varieties, Dixie Triumph being generally the latest variety of the three tested. Thus, it is not improbable that seasonal conditions may produce a state of succulency in a 41-day boll formed late in the season comparable to that of a 34-day boll formed early in the season.

[4] Standard error is used in preference to "probable error." For discussion, see Engledow, F. L., and Yule, G. Udny (4).

TABLE 2.—*Results of an average puncture test upon 10 cotton bolls of 3 varieties at 27, 34, and 41 days of age, 1925*

Series No.	High nitrogen						Low nitrogen					
	Date of bloom	Date of test	Wall thickness	Boll diameter	Age	Pressure [a]	Date of bloom	Date of test	Wall thickness	Boll diameter	Age	Pressure [a]
	Cleveland 12						Cleveland 12					
			Cm.	*Cm.*	*Days*	*Grams*			*Cm.*	*Cm.*	*Days*	*Grams*
1	July 10	Aug. 6	0.20	3.67	27	[b]513±4.4	July 10	Aug. 6	0.19	3.63	27	542
	...do	Aug. 13	.20	3.75	34	537±3.7	...do	Aug. 13	.17	3.45	34	543
	...do	Aug. 20	.16	3.29	41	500±5.8	July 11	Aug. 21	.16	3.41	41	518
2	July 15	Aug. 11	.17	3.29	27	507	July 15	Aug. 11	.18	3.55	27	571
	July 16	Aug. 19	.17	3.53	34	517	July 16	Aug. 19	.16	3.33	34	504
	...do	Aug. 26	.15	3.35	41	530	...do	Aug. 26	.15	3.25	41	520
3	July 21	Aug. 17	.17	3.22	27	518	July 21	Aug. 17	.17	3.27	27	534
	July 22	Aug. 25	.18	3.40	34	552	July 22	Aug. 25	.16	3.28	34	526
	July 24	Sept. 3	.15	3.39	41	567	July 24	Sept. 3	.15	3.35	41	587
Incomplete.	July 8	Aug. 4	.22	3.64	27	535	July 8	Aug. 4	.18	3.37	27	551
	July 29	Aug. 25	.17	3.23	27	564	July 28	Aug. 24	.17	3.24	27	549
	July 30	Sept. 2	.18	3.30	34	582	July 30	Sept. 2	.16	3.17	34	570
	Carolina Webber						Carolina Webber					
1	July 9	Aug. 5	0.22	3.56	27	567±3.8	July 9	Aug. 5	0.21	3.55	27	549
	...do	Aug. 12	.20	3.61	34	525±3.7	...do	Aug. 12	.20	3.48	34	570
	...do	Aug. 19	.19	3.47	41	529±4.6	...do	Aug. 19	.17	3.43	41	568
2	July 15	Aug. 11	.22	3.24	27	590	July 14	Aug. 10	.21	3.50	27	584
	July 16	Aug. 19	.19	3.44	34	541	July 16	Aug. 19	.19	3.44	34	547
	...do	Aug. 26	.18	3.30	41	556	...do	Aug. 26	.18	3.43	41	574
3	July 21	Aug. 17	.20	3.35	27	561	July 21	Aug. 17	.21	3.34	27	552
	July 22	Aug. 25	.19	3.50	34	595	July 22	Aug. 25	.18	3.27	34	554
	...do	Sept. 1	.18	3.43	41	595	...do	Sept. 1	.19	3.44	41	620
Incomplete.	July 7	Aug. 3	.21	3.52	27	517	July 7	Aug. 3	.23	3.39	27	532
	July 29	Aug. 25	.22	3.50	27.	592	July 29	Aug. 25	.22	3.30	27	581
	July 30	Sept. 2	.21	3.38	34	599	July 30	Sept. 2	.20	3.13	34	552
	Dixie Triumph						Dixie Triumph					
1	July 10	Aug. 6	0.19	3.48	27	493±3.6	July 10	Aug. 6	0.20	3.51	27	554
	...do	Aug. 13	.20	3.65	34	514±4.8	...do	Aug. 13	.18	3.51	34	555
	...do	Aug. 20	.17	3.55	41	481±4.3	...do	Aug. 20	.16	3.44	41	527
2	July 15	Aug. 11	.18	3.33	27	510	July 16	Aug. 12	.19	3.33	27	553
	July 16	Aug. 19	.18	3.41	34	502	...do	Aug. 19	.18	3.32	34	538
	July 17	Aug. 27	.17	3.41	41	533	July 17	Aug. 27	.19	3.46	41	552
3	July 21	Aug. 17	.18	3.38	27	571	July 21	Aug. 17	.18	3.29	27	518
	July 23	Aug. 26	.18	3.32	34	526	July 23	Aug. 26	.16	3.13	34	526
	July 22	Sept. 1	.16	3.30	41	637	July 22	Sept. 1	.15	3.20	41	560
Incomplete.	July 8	Aug. 4	.21	3.68	27	552	July 8	Aug. 4	.21	3.70	27	593
	July 28	Aug. 24	.17	3.32	27	516	July 28	Aug. 24	.17	3.13	27	528
	July 30	Sept. 2	.17	3.22	34	576	July 30	Sept. 2	.17	3.10	34	541

[a] Each figure for pressure represents an average of 62 to 98 punctures of innermost boll wall.
[b] Standard error.

A nitrogen deficiency seems to produce tougher bolls on Dixie Triumph from blossoms formed to July 17, inclusive, with a shift to tougher bolls from the high-nitrogen plot from blossoms produced after the above date. It appears that the same general tendency exists in the Cleveland variety, though there are a few exceptions.

There are seven pairs of boll samples for comparison of the Dixie Triumph variety from blossoms formed to July 17, inclusive. Bolls grown under conditions of low nitrogen show the greatest resistance to puncture at 27, 34, and 41 days, while bolls formed July 21 to 30, inclusive, show the tendency for greater toughness under conditions of high-nitrogen supply, which is particularly true of the 34-day and 41-day bolls tested September 1 and 2. All bolls tested to

August 27, inclusive, with two exceptions, therefore, are tougher with a low supply of nitrogen, and those tested later are tougher with a high supply of nitrogen.

The five pairs of boll samples of Cleveland 12 tested before August 19 show tougher boll walls with a low nitrogen supply, while five of the pairs tested beginning on that date offer greater resistance to penetration with a high-nitrogen supply. The two exceptions are 41-day bolls.

It appears that bolls of Carolina Webber at 27 days of age are usually tougher with a high-nitrogen supply, regardless of the period of development or date of test, but as they approach the stage of maturity represented by 41 days, they are tougher in general under low-nitrogen conditions. The differences in the boll reactions of the three varieties should be noted because of the probable relations to plant metabolism. The relative rates of toughening of boll walls of Cleveland 12 and Dixie Triumph from plants with a low and a high nitrogen supply, respectively, were reversed about August 19 to 25, for the toughest bolls in general at 27, 34, or 41 days occur on low-nitrogen plants before these dates and in general on high-nitrogen plants after these dates. Such differences in toughness may be indicative of changes in the relative levels of plant metabolism under the two conditions, with shifts in the relative rates of supply, or proportion of substances supplied to bolls occurring about August 19 to 25.

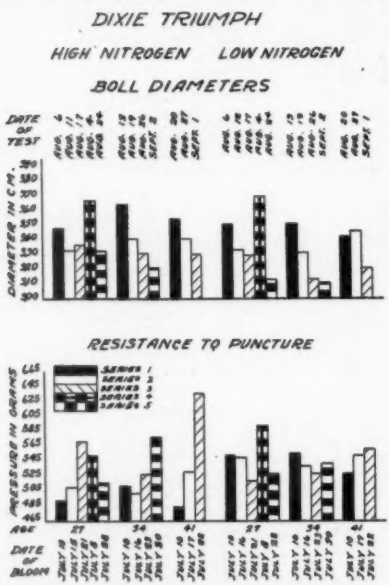

FIG. 5.—Diameter and resistance to puncture, Dixie Triumph cotton bolls, 1925

Variations in the puncture tests of Webber bolls do not present as clearly the probable relations, but the fact that most 27-day bolls, both early and late, are toughest with high nitrogen and the 41-day bolls toughest with low nitrogen seems to indicate that changes in the rate of supply, or proportions of the substances supplied the boll, occur at regular stages in the development of the individual boll rather than at a definite stage of plant development, as in Cleveland 12 and Dixie Triumph.

The results presented show, therefore, that a pressure test on cotton bolls of the ages studied does detect certain differences which are due presumably to the conditions of fertility under which the plants were grown.

Regardless of conditions of fertility or the variety, however, there are certain tests in the series which depart considerably from the

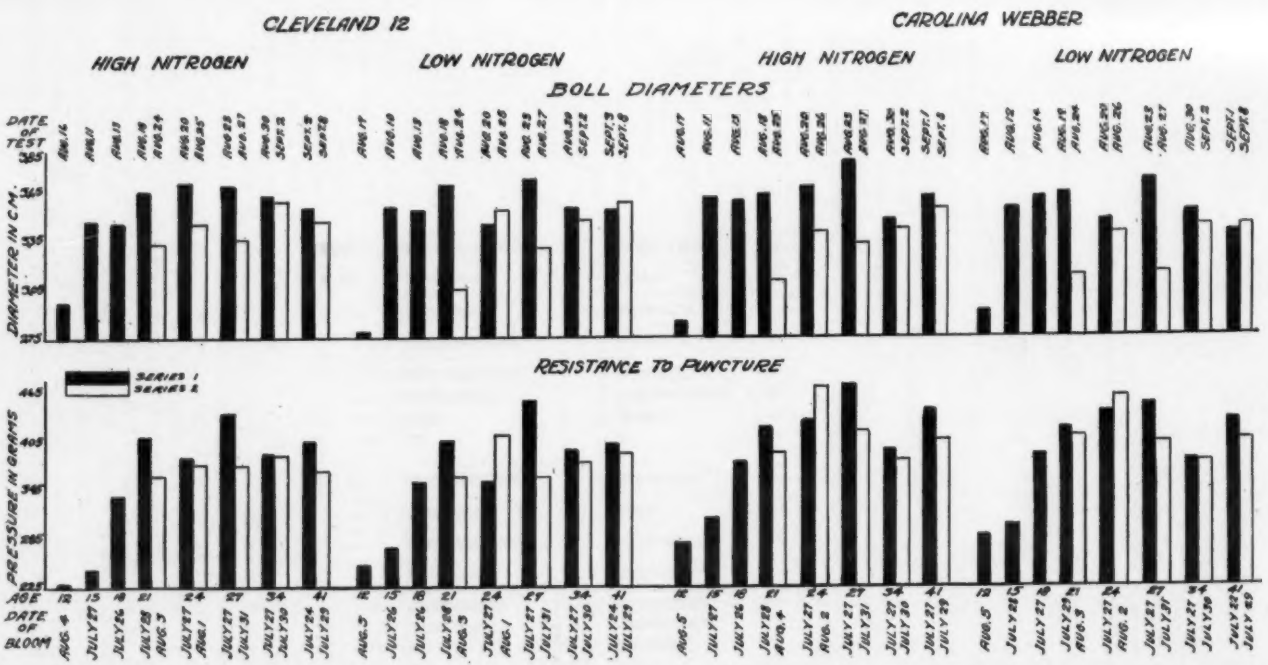

FIG. 6.—Diameter and resistance to puncture, Cleveland 12 and Carolina Webber cotton bolls, 1926

average, such as the relatively high pressures necessary to puncture most of the 34-day and 41-day bolls on September 1, 2, and 3. A few such exceptions occurred in 1924 and 1926. A study of records of temperature, humidity, rainfall, soil moisture, and evaporation from white and black atmometers inclines the author to believe that certain combinations of environmental conditions at the day of, and for two or three days preceding, the test are partly responsible, though it has not been possible to evaluate these with any degree of certainty.

RESULTS OF PUNCTURE TESTS, 1926

The same varieties were used in 1926 as in 1925, and it was planned to have approximately the same conditions of high and low nitrogen, but the plot selected proved to be so fertile that no appreciable difference in the plants could be detected until late in the season, even though the nitrate of soda was applied as in 1925. An examination of the data in Table 3 and Figures 6 and 7 shows that no general and significant differences are to be found in the toughness of bolls from high and low nitrogen plots.

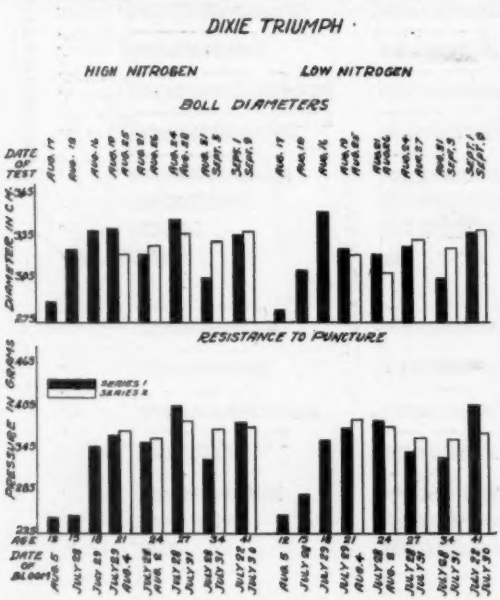

FIG. 7.—Diameter and resistance to puncture, Dixie Triumph cotton bolls, 1926

There is a progressive increase in boll toughness with age in every series from 12 to 21 days, inclusive. This progressive increase does not occur from 24 days to 41 days, thus indicating that the age of the boll is not a determining factor for toughness throughout its entire period of development. A daily series of boll-diameter measurements in 1927, which are not presented in this paper, show that the boll reached practically its full size in 20 days. Thus it seems that in general the period of boll development, characterized by rather regular increase in resistance to puncture, ceases at about full size, though this may occasionally continue to 41 days, as seen in certain instances throughout these tests.

It will be noted that bolls of the Webber variety were generally the toughest and that those of Dixie Triumph and Cleveland 12 assume variable relations to each other at almost every succeeding test.

TABLE 3.—*Results of an average puncture test upon 10 cotton bolls of 3 varieties at 12, 15, 18, 24, 27, 34, and 41 days of age, 1926*

Series No.	High nitrogen: Date of bloom	Date of test	Wall thickness	Boll diameter	Age	Pressure [a]	Low nitrogen: Date of bloom	Date of test	Wall thickness	Boll diameter	Age	Pressure [a]
	Cleveland 12						**Cleveland 12**					
			Cm.	*Cm.*	*Days*	*Grams*			*Cm.*	*Cm.*	*Days*	*Grams*
	Aug. 4	Aug. 16	0.17	2.96	12	[b]229±2.4	Aug. 5	Aug. 17	0.17	2.78	12	249
	July 27	Aug. 11	.19	3.47	15	249±3.2	July 26	Aug. 10	.21	3.55	15	272
	July 26	Aug. 13	.19	3.46	18	338±4.2	...do.....	Aug. 13	.20	3.51	18	353
1	July 28	Aug. 18	.21	3.65	21	410±7.4	July 28	Aug. 18	.19	3.68	21	405
	July 27	Aug. 20	.19	3.70	24	383±5.4	July 27	Aug. 20	.17	3.44	24	352
	...do.....	Aug. 23	.22	3.68	27	438±6.0	...do.....	Aug. 23	.22	3.71	27	454
	...do.....	Aug 30	.19	3.60	34	388±2.8	...do.....	Aug. 30	.18	3.54	34	392
	July 24	Sept. 3	.18	3.55	41	405±4.4	July 24	Sept. 3	.17	3.53	41	401
	Aug. 3	Aug. 24	.18	3.33	21	363	Aug. 3	Aug. 24	.17	3.05	21	362
	Aug. 1	Aug. 25	.18	3.45	24	381	Aug. 1	Aug. 25	.19	3.52	24	412
2	July 31	Aug. 27	.18	3.35	27	373	July 31	Aug. 27	.18	3.30	27	362
	July 30	Sept. 2	.20	3.59	34	387	July 30	Sept. 2	.20	3.47	34	377
	July 29	Sept. 8	.18	3.46	41	367	July 29	Sept. 8	.19	3.57	41	390
	Carolina Webber						**Carolina Webber**					
	Aug. 5	Aug. 17	0.19	2.84	12	276±2.6	Aug. 5	Aug. 17	0.18	2.90	12	288
	July 27	Aug. 11	.22	3.60	15	310±4.5	July 28	Aug. 12	.20	3.53	15	301
	July 26	Aug. 13	.22	3.59	18	380±4.3	July 27	Aug. 14	.22	3.59	18	395
	July 28	Aug. 18	.22	3.62	21	420±4.3	July 29	Aug. 19	.19	3.62	21	422
1	July 27	Aug. 20	.20	3.66	24	428±3.9	July 27	Aug. 20	.17	3.47	24	441
	...do.....	Aug. 23	.23	3.81	27	469±4.8	...do.....	Aug. 23	.20	3.70	27	448
	...do.....	Aug. 30	.20	3.46	34	394±4.8	...do.....	Aug. 30	.17	3.50	34	380
	July 22	Sept. 1	.20	3.61	41	443±5.7	July 22	Sept. 1	.18	3.39	41	431
	Aug. 4	Aug. 25	.19	3.10	21	390	Aug. 3	Aug. 24	.19	3.13	21	411
	Aug. 2	Aug. 26	.22	3.40	24	469	Aug. 2	Aug. 26	.20	3.39	24	457
2	July 31	Aug. 27	.21	3.32	27	413	July 31	Aug. 27	.19	3.24	27	402
	July 30	Sept. 2	.20	3.41	34	382	July 30	Sept. 2	.19	3.43	34	379
	July 29	Sept. 8	.20	3.54	41	405	July 29	Sept. 8	.18	3.44	41	405
	Dixie Triumph						**Dixie Triumph**					
	Aug. 5	Aug. 17	0.18	2.90	12	246±4.2	Aug. 5	Aug. 17	0.16	2.84	12	253
	July 28	Aug. 12	.19	3.28	15	250±2.9	July 28	Aug. 12	.18	3.12	15	281
	July 29	Aug. 16	.19	3.40	18	346±4.3	July 29	Aug. 16	.19	3.54	18	357
	...do.....	Aug. 19	.19	3.42	21	361±3.8	...do.....	Aug. 19	.17	3.26	21	375
1	July 28	Aug. 21	.17	3.23	24	357±5.0	July 28	Aug. 21	.16	3.23	24	386
	...do.....	Aug. 24	.19	3.47	27	407±5.0	...do.....	Aug. 24	.16	3.28	27	348
	...do.....	Aug. 31	.16	3.06	34	330±5.5	...do.....	Aug. 31	.14	3.06	34	334
	July 22	Sept. 1	.18	3.37	41	385±5.6	July 22	Sept. 1	.18	3.39	41	407
	Aug. 4	Aug. 25	.17	3.23	21	372	Aug. 4	Aug. 25	.17	3.22	21	388
	Aug 2	Aug. 26	.17	3.29	24	363	Aug. 2	Aug. 26	.16	3.10	24	379
2	July 31	Aug. 27	.19	3.38	27	386	July 31	Aug. 27	.18	3.33	27	364
	...do.....	Sept. 3	.19	3.32	34	374	...do.....	Sept. 3	.18	3.28	34	361
	July 30	Sept. 9	.17	3.39	41	376	July 30	Sept. 9	.18	3.41	41	370

[a] Each figure for pressure represents an average of 62 to 98 punctures of innermost boll wall.
[b] Standard error.

BOLL DIAMETERS

There was no apparent relation between boll size and toughness in 1924 or 1925, as seen in Figures 3, 4, and 5, but the similarity of the graphs for 1926, as seen in Figures 6 and 7, is quite evident. If the 24-day-old bolls tested on August 25 and 26, 1926, had not shown relatively greater toughness than others in the series, the resemblance of the graphs would be very striking.

The results of 1924 gave some indication that bolls of 27 or 34 days of age when formed later in the season are somewhat smaller than bolls of the same ages formed earlier. The 41-day bolls were rather

variable in 1924 as they were throughout the three seasons. Again in 1925 bolls at the ages of 27 and 34 days were generally smaller when formed later in the season. Bolls formed later in the season of 1926 showed the same general tendency to be smaller at 21, 24, 27, and 34 days of age. Martin, Ballard, and Simpson (*13*) have reported that later bolls of the Lone Star variety grown in Texas were consistently smaller than the early ones. This was ascribed to a drought which checked the growth of the plants after the first week in August.

That 41-day bolls do not show a more regular tendency to be smaller late in the season, aside from the variations to be expected from 10-boll samples, may be because some of the earlier samples were dried almost to the point of cracking open, while later samples were succulent. It is quite probable that such changes in the condition of succulency cause considerable variation in the diameter of older bolls, though the extent of these differences is not known. Even daily variations in the diameter of bolls are known to occur. In an experiment of 1927, to be published later, contractions of 0.01 to 0.11 centimeter occurred between 9 a. m. and 4.30 p. m. with bolls from 20 to 49 days of age. The evaporating power of the air was not at all excessive as shown by black and white atmometers, and the soil moisture was abundant. Many of the measurements in 1925 and 1926 were made at times of very hot weather and low soil moisture, which might cause greater variations in boll diameter. The data of Table 2 give indications of a possible shrinkage of bolls from plants grown with a low nitrogen supply under the dry conditions of 1925. A comparison of the diameters of the 27-day and 34-day bolls of the same blossoming date grown with a low supply of nitrogen shows that 10 of the 12 samples are smaller at 34 days. The season was very dry and by the time of the later tests the plants in both the low and high nitrogen plots were showing signs of great water deficiency during the hot hours of the day. The low-nitrogen plants suffered particularly as was shown by the fact that they changed from a bright green to a light yellow color and shed all the young fruit and quite a number of the lower leaves. The shrinkage indicated here, however, was greater than that measured in 1927.

BOLL-WALL THICKNESS

Immediately after the puncture tests of 1925 and 1926, each boll was cut transversely along the circumference of the punctures and two measurements of wall thickness made at opposite points. The measurements were made to hundredths of a centimeter with a caliper that could be read to that degree of accuracy. Each figure for wall thickness in Tables 2 and 3 is the average of a 10-boll sample, or an average of 20 such measurements.

The data presented for 1925 in Table 2 show no evident relation of wall thickness and toughness. The figures for wall thickness do not follow the general trend of those for toughness within the ordinary range, nor is there any unusual thickness of wall associated with the rather tough bolls found in several of the tests made on September 1, 2, and 3.

No pronounced correlation of boll diameter and wall thickness can be found, though such a relation is indicated at the ages of 27 and

34 days. The figures for Cleveland 12 and Dixie Triumph particularly show that, in general, the larger the boll the thicker the wall will be. Webber generally produces the largest bolls and thickest walls. although the relation between boll diameter and wall thickness seems more variable for this variety.

A decrease in wall thickness of the 41-day bolls generally occurs for all varieties, depending largely on the degree to which the final drying of the boll has proceeded.

Table 3 presents the data on wall thickness for 1926. The results for wall thickness show fairly close agreement with those for boll diameter and boll toughness at 21, 24, 27, and 34 days of age. The similarity of the results can be extended to 15 and 18 days if wall thickness and boll diameter only are considered.

The decrease in wall thickness that occurs in the later stages of boll development is indicated in most of the 41-day measurements. This is in agreement with the results of 1925.

RELATION OF BOLL SIZE, BOLL-WALL THICKNESS, AND TOUGHNESS OF BOLL TO COTTON LOSS FROM BOLL-WEEVIL ATTACK

In 1925 and 1926, while the experiments reported in this paper were in progress, independent studies were made by Dunnam (*3*) of boll-weevil damage to bolls of known ages on the same varieties used for the needle-puncture tests. Not only were the varieties the same but the seed was obtained from the same source. The plants were not grown on the same plots, however, nor were the same amounts of fertilizer applied. Regardless of these differences, mention of some of the results does not seem amiss.

The boll-weevil studies for 1925 have been reported by Dunnam (*3*) and the results for both years will soon appear.[5] Weevils were caged on 2,833 bolls in the weevil-damage experiments of Fenton and Dunnam,[5] while about 136,000 needle punctures were made on 1,510 bolls in 1925 and 1926. Fenton and Dunnam found that the resistance of a boll to weevil damage progressively increases with boll age. Two of the varieties suffered less than 10 per cent cotton loss from weevil attack after the bolls were 20 days old. A third variety was more susceptible, the weevil being able to cause more than 10 per cent damage until the bolls were 30 days old. The results obtained by the writer from the needle-puncture tests do not show a close correlation of either resistance to puncture, wall thickness, or boll size to percentage of cotton loss from weevil attack. It is realized that the boll weevil does not puncture the boll wall by mere pressure, yet the toughness of the inner wall may be of some value, for Fenton and Dunnam[5] point out that dissections of older bolls often show that the hole made by the weevil for the reception of the egg extends only to the inner membrane surrounding the cottonseed and lint in each locule.

It should also be kept in mind that the greatest weevil damage occurs during the first 20 to 30 days of boll growth, while needle-puncture tests were begun with 20-day bolls for a few varieties in 1924, with 27-day bolls in 1925, and with 12-day bolls in 1926.

[5] FENTON, F. A., and DUNNAM, E. W. THE BIOLOGY OF THE COTTON BOLL WEEVIL AT FLORENCE, S. C. [Unpublished manuscript.]

Bolls with the toughest walls, such as Cleveland 12 in 1924, suffered the least cotton loss until about 27 days in the early tests, while the bolls that remained longest in a comparatively tender state, as in the Dixie Triumph variety, suffered the greatest cotton loss. In the tests of the following years, the walls of Webber bolls have generally been the toughest and the thickest, although this variety has not suffered the lowest percentage of cotton loss. A larger number of records on bolls of individual ages are necessary before definite conclusions can be drawn.

SUMMARY

Cotton boll size, wall thickness, and toughness, as measured by resistance to needle puncture, have been studied on bolls of several ages from different varieties grown under two conditions of fertility. The tests were conducted during three seasons of growth.

There was an increase in toughness of boll wall to about 21 days, at which time the bolls had practically attained their full size. After this time the age of the boll was not a chief factor.

The conditions during the developmental period probably influence the relative toughness of walls, as shown by the generally more tender bolls in the later series of 1926 contrasted with the tougher bolls in some of the late series of 1924.

The conditions of fertility may be reflected in the resistance to puncture if the contrast in fertility conditions is sufficiently great.

Varietal differences in toughness of wall are evident though not constant. Bolls of Webber were toughest late in the season of 1924 and in general throughout the seasons of 1925 and 1926. The relative toughness of the bolls of Dixie Triumph and Cleveland 12 at different ages was variable.

The bolls of Webber are, in general, largest and the walls thickest.

No close correlation was found between boll size, wall thickness, or wall toughness and the percentage of cotton loss from boll-weevil attack as studied by Fenton and Dunnam.[6]

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